PURPLE NUTSEDGE (*Cyperus rotundus*) DYNAMICS IN GLYPHOSATE TOLERANT CROPS

By

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This manuscript is dedicated to the memory of my grandfathers,

Thomas Edenfield and Luther Sasser

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PURPLE NUTSEDGE (*CYPERUS ROTUNDUS*) DYNAMICS IN GLYPHOSATE-TOLERANT CROPS

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Purple nutsedge (*Cyperus rotundus* L.) is a perennial weed that plagues agricultural areas of the world. Glyphosate is a broadspectrum, non-selective herbicide with, until recently, limited value for selective weed control in agronomic crops. However, genetic engineering has led to development of cotton and soybean varieties with glyphosate tolerance. Studies were implemented to evaluate glyphosate for purple nutsedge management in glyphosate-tolerant cotton and soybean. Purple nutsedge control increased when applications were delayed from 2 week-old plants to 5 week-old plants, but the delay in application increased purple nutsedge competition causing cotton injury. Sequential applications of glyphosate were more effective than a single application. The best weed control while providing cotton with the greatest competitive advantage was observed when glyphosate at 0.85 kg/ha was applied postemergence (POST) at 3-leaf

cotton followed by glyphosate POST-directed at 8-leaf Glyphosate had little impact on cotton 'Deltapine 5415RR' boll development when applied up to 8 leaf cotton, and yields were generally not reduced until applied at 12-leaf cotton. In the three-year glyphosate tolerant soybean study, glyphosate was more effective than chlorimuron or imazaquin in controlling purple nutsedge and depleting tubers in the first year of experimentation However, by mid-season of the second year purple nutsedge populations were reduced among all herbicides and each were comparable Similar results were noted in the three year cotton experiment Glyphosate was better for purple nutsedge control in cotton than monosodium methanearsonate (MSMA) the first year, but MSMA and glyphosate was comparable provided cultivation was added with MSMA. After 3 years, glyphosate, MSMA, and cultivation alone substantially reduced nutsedge populations and there was no difference in yield between any treatment. Benzyladenine (BA) plus gibberrelic acid (GA) induced breaking apical dominance through the purple nutsedge tuber chain thus increasing vegetative growth at the expense of tuber development, but BA plus GA did not facilitate purple nutsedge control with herbicides. Shade reduced the growth and development of purple nutsedge, and served to increase glyphosate absorption and translocation in shoots and tubers of purple nutsedge.

CHAPTER 1
INTRODUCTION

Purple nutsedge (*Cyperus rotundus* L.) has been identified as one of the world's worst weeds in the major agricultural areas of the world (Holm 1969). This weed can be found throughout warm climates, and thrives in cultivated crops and other disturbed lands. Purple nutsedge is limited only by low temperatures and moisture (Bendixen and Nandihalli 1987). Purple nutsedge is an aggressive competitor for moisture and nutrients, and has been reported to produce allelopathic compounds that adversely affect the growth and development of crops (Friedman and Horowitz 1970). Native to India, this sedge has dark green leaves, a three-sided stem and may grow to 100 cm in height on arable land (Holm et al. 1977). Purple nutsedge is also known to the world as "nutgrass" due to the extensive underground system of bulbs, rhizomes and tubers (Hauser 1962a). The plant generally produces numerous seeds, however, dispersal is primarily by bulbs and tubers, since only a fraction of the seeds are viable (Justice and Whitehead 1946).

Biology

Tubers are the source of most new purple nutsedge plants (Holm et al. 1977). A tuber may have ten or more buds (Horowitz 1972b), each capable of producing an aerial shoot. Generally, the bud on the apex of the tuber will initiate germination and produce a white fleshy rhizome. The rhizome grows vertically and becomes enlarged near the soil

surface often called a "basal bulb" (Horowitz 1992) Basal bulbs contain meristems for vegetative growth of roots, rhizomes, leaves and flower shoots (Hauser 1962a, Ranade and Burns 1925 Stoller and Sweet 1987) Subterranean rhizomes which are formed from the basal bulb nodes may grow up to 30 cm in length The terminal end of the rhizome may develop additional tubers These new tubers, in turn, will either produce a new basal bulb with aerial shoots, or produce additional rhizomes. Additional rhizomes, in turn will produce more tubers resulting in a tuber chain (Barry et al 1992)

Basal bulbs sometimes called corms (Wills and Briscoe 1970) may fuse with tubers to form a propagule with extra starch (Hammerton 1974) The difference between bulbs and tubers is based on their activity; bulbs immediately produce aerial shoots while tubers tend to be temporarily dormant (Hauser 1962a) The apical bud of the tuber inhibits axillary bud sprouting and the tuber at the morphological apex of a rhizome tuber chain prevents sprouting in the chain. However, apical dominance can be broken with cultural practices such as tillage, which separate tubers from each other (Hohn et al 1977) Nonetheless if left undisturbed, a system of bulbs and underground tubers and rhizomes are formed which function as a continuous plant unit for at least one season.

Tuber Dynamics

Soil temperatures > 20C are the primary stimulus responsible for breaking purple nutsedge tuber dormancy (Bayer 1987, Horowitz 1972b, Sun and Nishimoto 1995) Tubers will begin to sprout aerial shoots within 7 to 10 days (Hauser 1962b) Tuber enlargements can be formed in as little as 10 to 20 days after shoot emergence (Ranada and Burns 1925), or as long as 4 to 6 weeks (Hauser 1962a). Hauser (1962b) found the

production of tubers possessing dormancy to be low in the first few weeks of nutsedge development, with mostly basal bulbs produced from the parental tuber. Generally, in the first 4 weeks after shoot emergence, all tuber enlargements (basal bulbs) at the terminal end of developing rhizomes will produce new plants. The formation of a dormant tuber will begin at 4 to 8 weeks after shoot emergence, following the first appearance of flowers (Hansel 1962b, Stoller and Sweet 1987). Ten weeks after shoot emergence, Hauser (1962b) reported most of the tubers produced were solitary, whereas by 14 weeks after emergence chains of four tubers were established.

Although the production of tubers varies according to environmental conditions (Smith and Frick 1937), the infestation potential is of great importance since tubers may be formed within 10 to 20 days after shoot emergence. Once a tuber has been formed, it is capable of surviving to produce a viable plant even if the parental plant is destroyed (Hammerton 1974, Horowitz 1972b). Tubers may lie dormant for an extended period of time and have been shown to possess secondary dormancy characteristics (Neeser et al. 1997).

Many investigators have cited the extensive tuber production by purple nutsedge. Hauser (1962b) reported that by 6 weeks after shoot emergence, the subterranean network of bulbs, tubers and rhizomes possessed a mass greater than that of the foliage. Smith and Frick (1937) reported that a single tuber produced 146 bulbs and tubers in 14 months and Rao (1968) found one parental tuber produced 59 basal bulbs and tubers in 90 days. Hauser (1962b) reported that tubers planted at 30.5 cm intervals could produce more than 1 million plants/ha with 2 million bulbs and tubers in the first year of infestation. By the

end of the second season, more than 2 million plants/ha had been produced with 5 million bulbs and tubers/ha (Hauser 1962b)

Investigators report that most tubers are found in the top 20 cm of the soil, and rarely found beneath 30 cm (Stoller and Sweet 1987 Smith and Frick 1937) However tubers may be distributed deeper in course textured soils. The germination of tubers is higher and shoots emerge faster when close to the soil surface However reports have indicated shoots capable of emerging from tubers as deep as 45 cm (Horowitz 1965)

Agricultural Importance

Purple nutsedge reduces the yield of important agricultural crops (Keeley 1987 Elmore et al 1983) The weed thrives under ideal crop conditions including high soil moisture, high soil fertility and high temperatures Purple nutsedge has been cited as a significant weed problem in 52 crops of 92 countries (Holm et al 1977, Bendixen and Nandihalli 1987) Though the weed is relatively short in stature, it is very aggressive Reproductive propagules (tubers) provide for fast initial growth enabling an early season advantage in crops. Elmore et al (1983) reported 1 week after planting purple nutsedge was significantly taller than cotton

Purple nutsedge will generally absorb more nutrients than a given crop Guantes (1974) reported purple nutsedge growing with cotton absorbs twice as much nitrogen and one-third more potassium than cotton.

Purple nutsedge has been reported to be sensitive to shade (Ranade and Burns 1925) Once crops form a dense canopy the weed is shaded and the competitive potential of purple nutsedge is reduced. Patterson (1982) reported that shading results in

a reduction in tuber production by decreasing the partitioning of plant biomass to tubers and rhizomes, with an increase of partitioning into leaves. Crop interference also reduces tuber number and size. However, purple nutsedge can still be competitive under a crop canopy since 44 to 70% of the weed's dry weight in underground rhizomes and tubers (Williams 1982).

Another concern with purple nutsedge in a cropping system is the allelopathic potential of decaying tissues. Purple nutsedge can produce 10 to 30 million bulbs and tubers/ha each season (Hauser 1962a). Analysis of tuber residues in the soil have revealed various phenolic compounds. Extracts from these residues inhibited seed germination of several crop plants (Friedman and Horowitz 1970).

Evidence for allelopathy has been documented from both tuber and foliage extracts applied to test species. Growth reduction of crop species has also been observed when planted where purple nutsedge had previously been present (Chivinge 1985; Friedman and Horowitz 1970). Friedman and Horowitz (1970) reported that extract from purple nutsedge roots and tubers inhibited germination and radicle elongation of barley (*Hordeum distichum* L.). However, another experiment demonstrated that germination of cotton, maize, or soybeans (*Glycine max* L.) was not affected by purple nutsedge residues in the soil (Chivinge 1985). Though the growth and development of maize or soybean were not adversely affected, Chivinge (1985) reported that soil previously infested with purple nutsedge significantly reduced cotton growth including shortened and deformed roots.

Methods of Control

Purple nutsedge has been designated as one of the world's worst weeds because it is widely distributed, a problem in many crops, and is difficult to control. Traditional weed control strategies generally include tillage and/or herbicides. Control methods would be greatly improved if dormancy was relatively short allowing all buds to sprout at the same time. Sustainable control is limited because many tubers remain dormant in the soil for an extended period of time, thus eluding typical control measures.

Frequent tillage has resulted in satisfactory control of purple nutsedge. Tillage may kill tubers provided that the roots which supply moisture are cut (Andrews 1940). Tubers in their natural state contain approximately 85% water. The water content of tubers is relevant in tillage operations. Tillage will bring tubers to the surface, thus reducing their numbers by desiccation. Dessication to < 15% water is lethal while a reduction in moisture content will reduce viability (Smith and Frick 1937).

Cultivation can increase the level of purple nutsedge infestation. Rao (1968) reported cultivated areas had twice the population of uncultivated areas. This phenomenon can be attributed to a break in the apical dominance of the tuber chain during tillage, inducing sprouting of dormant tubers. However, multiple tillage operations timed over short intervals, have resulted in good control. Eradication of purple nutsedge has been achieved with thorough discing at two to three week intervals for two growing seasons (Westmoreland et al. 1955).

Herbicides are generally an essential component for weed control in production agriculture. Most weeds in production agriculture are controlled with a combination of

herbicide treatments including soil-applied preplant incorporated (PPI) and/or preemergence (PRE) to control grasses and certain broadleaf weeds. These treatments are often followed by a postemergence treatment to control weeds which emerge with, or following the crop. However, such weed control practices often reduce the competitiveness of other weeds while not affecting nutsedge. The few selective herbicides that have activity on purple nutsedge do not kill the nutsedge tubers, but rather the above-ground portion of the plant. Therefore, many selective herbicides in traditional cropping systems will only result in moderate control of purple nutsedge.

Historically, many herbicides have been evaluated for the control of purple nutsedge. Harmerton (1974) reported 2,4-D and paraquat reduced foliar growth but had little effect on tuber production. Thiocarbamate herbicides such as [S-ethyl dipropylcarbamothioate] EPTC and vernolate have also been used for control (Keeley and Thullen 1971). However, these herbicides inhibit cell division in meristematic regions of emerging shoots and thus have a limited effect on the unsprouted tuber. Therefore, repeat applications are often necessary to attain adequate control.

More recently, chemical control of purple nutsedge has been observed with sulfonylurea and imidazolinone herbicides. Herbicides that are more readily translocated throughout the plant have been more effective. Foliar applied herbicides must reach the underground network of attached bulbs and tubers to effectively control purple nutsedge. Translocation of the herbicide to the underground vascular system of the rhizomes is important because the vascular system may stay intact long after aerial shoots have been removed (Hauser 1962b).

Wills and Briscoe (1970) investigated the anatomy of purple nutsedge in an effort to aid research efforts to increase herbicide translocation. They reported that for a herbicide to reach the vascular system when applied to the leaf surface, it must penetrate the waxy upper surface, or move through the stomates and/or the thinly cutinized cells of the lower leaf surface. They proposed that disconnected vascular accessory bundles and/or immature vascular elements hinder the translocation of a phloem mobile herbicide from the leaf. However, glyphosate [N (phosphonomethyl)glycine] is a readily translocated herbicide and has been successful for the purple nutsedge control.

Glyphosate

Dr. John E. Franz discovered the herbicidal characteristics of glyphosate in 1970 (Franz et al. 1996). Glyphosate was introduced and marketed as the commercial product Roundup™ in 1974. The herbicide was labeled as a postemergence, broadspectrum, nonselective herbicide for the control of annual and perennial weeds. Glyphosate is one of the most widely used herbicides and is relatively nontoxic to mammals, birds, fish, insects and most bacteria (Franz et al. 1996). Another factor associated with the safety of glyphosate is that it does not bioaccumulate in animal tissue or crops. The Environmental Protection Agency (EPA) has designated glyphosate as a Class E compound. This rating is the least toxic class, and extensive research has resulted in no mutagenic, carcinogenic, teratogenic or allergenic activity (Franz et al. 1996).

Glyphosate is a systemic herbicide that is rapidly translocated to roots, rhizomes, and apical tissues. Glyphosate inhibits the enzyme 5 enolpyruvylshikimate-3-phosphate synthase (EPSPS). The inhibition of EPSPS prevents the plant from synthesizing

aromatic amino acids essential for plant growth ,resulting in the slow death of effected plants Due to this extensive translocation, hard to control perennial weeds such as nutsedge (*Cyperus*) johnsongrass (*Sorghum halepense* (L.) Pers), cogongrass (*Imperata cylindrica* L.) and quackgrass (*Agropyron repens* (L) Beauv) can be effectively controlled (Franz et al 1996)

The control of perennial weeds is most successful when foliar applied herbicides are absorbed and then translocated to underground storage organs (Sprankle et al 1975). Absorption must be quick and in sufficient quantity to kill the plant before metabolism can degrade the compound Investigators have reported that glyphosate is rapidly absorbed with a large portion translocated to underground rhizomes of purple nutsedge (Sprankle et al 1975 Zandstra and Nishimoto 1977) Sprankel et al (1975) reported that in quackgrass, glyphosate plus a surfactant was absorbed most rapidly within 4 hours after treatment and continued to increase (though not significantly) until 48 hours after treatment.

Zandstra et al (1974) reported purple nutsedge stands were reduced by 26 and 66% after a single treatment with glyphosate at 2 and 4 kg a.i./ha, respectively Four weeks after the first treatment sequential applications were applied They reported that the third glyphosate treatment reduced nutsedge density considerably but it was not eradicated. This experiment verified the weediness of purple nutsedge. When left undisturbed for 10 weeks after the third treatment the population had increased to 35 and 69% of the control

Age of the plant is an important factor in nutsedge control with glyphosate Zandstra et al (1974) reported that younger tuber chains of purple nutsedge were less dormant than older ones They reported that with 12 and 24 week old plants 53 and 55% of the tubers present sprouted when exposed to a cytokinin However, 74% of the tubers from chains of 6 week old plants sprouted. Tubers from 12 and 24 week-old plants treated with glyphosate sprouted 5 and 32%, respectively whereas, tubers from 6 week old plants did not germinate following glyphosate treatment

Glyphosate Tolerance

Glyphosate is a broadspectrum non selective herbicide, thus its use is limited for selective weed control in agronomic crops. However, with genetic engineering and advanced technology in cell culture techniques, in addition to traditional plant breeding, soybean and cotton varieties have been developed which possess tolerance to glyphosate The advent of herbicide tolerant crops provides significant alternatives for weed control in such crops

Steinrucken and Amrhein (1980) reported that the primary site of action with glyphosate is EPSPS EPSPS is a chloroplastic enzyme synthesized as a preprotein on free cytoplasmic ribosomes (Schmidt and Mushkind 1986) In the shikimic acid pathway of chloroplasts, EPSPS is the catalyst for aromatic amino acid biosynthesis including phenylalanine, tryptophane and tyrosine. The shikimic acid pathway can be regarded as one of the main metabolic pathways of a plant.

Padgette et al. (1995) have outlined the development and characterization of glyphosate tolerance. In these experiments, a glyphosate-tolerant soybean line was

obtained by introducing DNA from *Agrobacterium* sps. into soybean by the particle acceleration method. The expression of the *Agrobacterium* sps. EPSPS enzyme into soybean imparts glyphosate tolerance. Upon glyphosate treatment, the glyphosate-tolerant soybean plant remains unaffected by glyphosate because the introduced glyphosate-tolerant EPSPS enzyme produces an abundance of the enzyme needed for aromatic amino acid synthesis. With glyphosate tolerance imparted, no visual injury of herbicide damage was observed using glyphosate dosages up to 1.68 kg ae/ha. Padgette et al. also reported that a single dominant gene controls glyphosate tolerance.

Geugler and Geiger (1981) reported that after initial absorption into the leaf, glyphosate translocates and accumulates in growing meristematic regions. Barry et al (1992) investigated metabolic inactivation of glyphosate, in addition to modification of the target site by introducing glyphosate-tolerant EPSPS genes. This strategy resulted in improved expression of the protein not only in vegetative tissues, but also in meristematic tissues. In the method, a gene was cloned from a bacterium (*Achromobacter* sp. strain LBAA) that codes for glyphosate oxidoreductase (GOX). The combination of genetically engineering the genes for GOX protein and glyphosate-tolerant EPSPS into crops has provided vegetative and reproductive tolerance to glyphosate at the commercial level.

Zandstra et al. (1974) reported 26 and 67% purple nutsedge control after a single treatment with glyphosate at 2 and 4 kg a.e./ha, respectively. More recently, Bryson et al (1994) reported >75% control with glyphosate at 1.1 kg/ha in reduced tillage cotton. What is not fully understood are the environmental and physiological factors that explain why greater and more consistent purple nutsedge control can be obtained with glyphosate

in a cropping system. Further research is needed to investigate the use of glyphosate for the control of purple nutsedge in glyphosate-tolerant crops. Investigating nutsedge control in glyphosate-tolerant crops may provide insight into how the control of this weed may be improved in cropping and non-cropping systems.

The introduction of glyphosate tolerant crops has given farmers the unique option of non-selective weed control in such crops. These experiments are designed to further investigate the dynamics of purple nutsedge control with glyphosate in glyphosate tolerant crops. The objectives of this research for purple nutsedge control with glyphosate included the following: 1. determine the influence of glyphosate rate and time-of-application in cotton, 2. determine long term purple nutsedge control in transgenic cotton and soybean with glyphosate; 3. determine the dynamics of purple nutsedge tubers as affected by glyphosate in an established stand of purple nutsedge, 4. determine if the use of plant growth regulators can precondition purple nutsedge to improve control with glyphosate, and 5. study the effects of shading on the absorption and translocation of glyphosate in purple nutsedge.

CHAPTER II
PURPLE NUTSEDGE (*CYPERUS ROTUNDUS*) CONTROL WITH GLYPHOSATE IN GLYPHOSATE-TOLERANT COTTON (*GOSSYPIUM HIRSUTUM*) AND FALLOW

Introduction

Purple nutsedge (*Cyperus rotundus* L.) is a problematic weed in many agricultural areas of the world since it thrives in ideal crop conditions including high soil moisture, high soil fertility, and warm temperatures (Holm 1969). This weed has been reported to be a significant problem in 52 crops in 92 countries (Holm et al. 1977), and is cited as a serious or principle weed in rice (*Oryza sativa* L.), sugarcane (*Saccharum officinarum* L.), cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), and vegetables (Bendixen and Nandihalli 1987). Only low temperatures and moisture limit its distribution.

Though the weed is relatively short in stature, it is very aggressive. Reproductive propagules (tubers), which can be either quiescent or dormant in the soil, provide for fast initial growth enabling an early-season advantage in crops. Elmore et al. (1983) reported that by 1 week after planting purple nutsedge was taller than cotton. Purple nutsedge will generally absorb more nutrients than a given crop. Gaunties (1974) found that purple nutsedge growing with cotton absorbs twice as much nitrogen and one third more potassium than cotton.

In addition to competing with crops for water and nutrients, decaying purple nutsedge tissue may exhibit allelopathic properties. Extracts from both below- and above-ground residues have inhibited seed germination of several crop plants (Friedman and Horowitz 1970). Chivinge (1985) reported that cotton, corn, or soybean (*Glycine*

max L.) germination was not adversely affected however, soil previously infested with purple nutsedge reduced cotton growth including shortened and deformed roots

Purple nutsedge is a troublesome weed for cotton growers in the southeastern U S because it is difficult to control (Dowler 1998) Traditionally, control has been limited to cultivation, norflurazon [4-chloro 5-(methylamino)-2 (3-(trifluoromethyl)phenyl)-3(2*H*)-pyridazinone] preemergence DSMA [disodium methanearsonate] or MSMA [monosodium methanearsonate] post directed spray (PDS) (Bryson et al 1994) and more recently the use of glyphosate [*N* (phosphonomethyl)glycine] via hooded sprayers. Most cotton farmers have relied on a combination of cultivation and MSMA for purple nutsedge control However Charles (1995) reported that utilizing this combination has resulted in only moderate control of nutsedge foliage while actually increasing the production of tubers. This is of great significance when tubers may remain dormant in the soil for extended periods of time, avoiding control methods Charles (1995) reported an increase in tubers from 216 to 1510 per m^2 over a three year period when MSMA at 1 8 kg/ha PDS was used for purple nutsedge control In these same studies, where glyphosate was applied at 1 1 kg a.i./ha PDS tuber number increased from 216 to 383 per m^2 in cotton and yielded 26% greater than the MSMA treatment

Extensive data has been collected on the use of glyphosate for the control of purple nutsedge Glyphosate is a broadspectrum, non-selective herbicide which limits its use for selective weed control in agronomic crops. However the use of genetic engineering and advanced technology in cell culture techniques, in addition to traditional

plant breeding, have produced crop plants with tolerance to herbicides, including glyphosate (Barry et al 1992, Padgette et al 1995)

The advent of glyphosate-tolerant cotton provides a significant alternative for weed management. However, limited data is available that defines the optimal rate and timing of glyphosate application for purple nutsedge control in glyphosate-tolerant cotton The objective of these studies was to determine the affect of application timing and glyphosate rate on purple nutsedge control in glyphosate tolerant cotton

Previous studies have determined that purple nutsedge is sensitive to shade (Patterson 1982) thus increasing its susceptibility to herbicides such as glyphosate under reduced light intensities (Meosavi on and Dore 1979) An additional objective was to investigate purple nutsedge control with glyphosate in a fallow-area and to note any differences in control from purple nutsedge control in cotton which may be attributed to the development of a cotton canopy

Materials and Methods

Field experiments were conducted in 1997 1998, and 1999 at University of Florida's West Florida Research and Education Center located in Jay The soil was a Red Bay fine sandy loam with 2 2% organic matter. 69% sand 16% silt, and 15% clay (siliceous. thermic Rhodic Paleudult) Control with glyphosate was investigated in an area naturally infested with purple nutsedge Purple nutsedge populations were 100 150, and 300 plants per m^2 in 1997. 1998. and 1999 respectively Treatments were applied to nutsedge growing in glyphosate-tolerant cotton and in a separate non-crop fallow area. Pendimethalin [*N* (1 ethylpropyl)-3 4-dimethyl 2 6 dinitrobenzenamine] at 0 86 kg/ha

preplant incorporated and flnometuron [*N,N*-dimethyl *N'*-[3 (trifluoromethyl)phenyl]urea] at 1 17 kg/ha pre-emergence were applied the second week of May each year over both test sites to control annual grasses and broadleaf weeds. Neither herbicide has been shown to impact the growth of purple nutsedge. In the cotton experiment Deltapine 5415RR was planted immediately after the preplant herbicide application and typical production practices for Florida's panhandle were followed according to Sprenkel (1996)

The experimental design was a randomized block with four replications and a factorial arrangement of treatments Factors in the non-crop study were glyphosate rate (0 57, 0 86 and 1 14 kg a.i./ha), purple nutsedge size at initial herbicide application (8 to 15 cm and 20 to 30 cm tall) and number of applications (single POST over the-top vs two sequential POST over-the-top applications spaced four weeks apart)

Factors in the study with glyphosate tolerant cotton included glyphosate rate (0 57, 0 86 and 1 14 kg a.i./ha) nutsedge size at initial application (8 to 15 cm vs 20 to 30 cm tall), and application treatment (single POST over the-top, POST over the-top followed 4 weeks later by a second POST over-the-top treatment, and a POST over the-top application followed by a PDS treatment spaced 4 weeks apart) Plot size was 3 m by 6 m The initial herbicide treatment for the first and second purple nutsedge growth stage in each year were applied on 4 and 13 June 1997, 1 and 26 June 1998 and 31 May and 12 June, 1999, respectively

Treatments were evaluated for weed control and crop stunting 4 and 8 weeks after initial treatment (WAIT) based on a scale from 0 to 100, where 0 = no weed control and

100 = total weed control At the end of the season in the cotton experiment the center two rows of each plot were harvested using commercial equipment Data were subjected to analysis of variance for a three (glyphosate rate) by two (purple nutsedge growth size at initial application) by two or three (application treatment) factorial treatment arrangement in the glyphosate tolerant cotton experiment and the non-crop fallow study Means were separated using Fisher's Protected LSD Test at P = 0 05

Results and Discussion

Fallow Experiment

There was a treatment by year interaction ($P \leq 0$ 05) for purple nutsedge control 4 weeks after initial treatment (WAIT) in the non-crop study and thus the data were sorted by year Glyphosate rate and growth stage were significant ($P \leq 0$ 05) for purple nutsedge control 4 WAIT in each year which prevented pooling. Number of POST applications was not analyzed 4 WAIT since sequential treatments were made on the same day as the 4 week rating

In 1997 glyphosate at 0 57 kg/ha applied at the smaller purple nutsedge size resulted in better control 4 WAIT than when applied to the larger nutsedge (Table 2.1) Purple nutsedge size did not influence control with glyphosate at 0 85 kg/ha Increasing glyphosate rate to 1 14 kg/ha improved control provided applications were made to purple nutsedge 8 to 15 cm in height There was no difference between glyphosate at 0 86 or 1 14 kg/ha regardless of purple nutsedge size in 1998 (Table 2 1) However, less control was observed with glyphosate at 0.57 kg/ha when application was delayed to purple nutsedge 20 to 38 cm in height compared to glyphosate at 0 86 or 1 14 kg/ha In

1999, purple nutsedge control was less than 50% when glyphosate was applied at 0.57 kg/ha and less than 70% when applied at 0.86 kg/ha, regardless of nutsedge size at application (Table 2.1). Glyphosate applied at 1.14 kg/ha, however, provided better control of larger than smaller nutsedge (69 vs 84%) in 1999. A possible explanation for inferior control at the earlier growth stage may be due to excessive rain causing flooded conditions prior to application at the earlier growth stage resulting in stressed plants. Nonetheless, glyphosate at 1.14 was most effective regardless of purple nutsedge growth stage in 1999 (Table 2.1).

There was a treatment by year interaction ($P \leq 0.05$) for purple nutsedge control 8 WAIT in the non-crop study; thus data were sorted by year. Glyphosate rate, purple nutsedge growth stage, and number of applications were significant ($P \leq 0.05$) for purple nutsedge control 8 WAIT in each year which prevented pooling. In 1997, purple nutsedge control 8 WAIT was 17% better with sequential applications compared to a single POST treatment (Table 2.2). Similar observations were noted in 1998 and 1999 where sequential treatments resulted in 30 and 24% better control overall, respectively, than single treatments when evaluated 8 WAIT. Generally, growth stage did not affect control in 1997, but treating larger purple nutsedge positively influenced control 8 WAIT in 1998 and 1999 regardless of whether a single or sequential application was used. When a sequential application was employed, delaying application until the larger purple nutsedge growth stage resulted in 32 and 42% better control overall in 1998 and 1999 than when applied at the earlier growth stage (Table 2.2).

It should be noted that applications targeted towards the earlier growth stage resulted in better control 4 WAIT but by 8 WAIT, application to larger purple nutsedge provided better control Glyphosate is a foliar applied herbicide that is rapidly and tightly absorbed to soil resulting in no residual weed control (Ahrens 1994) A possible explanation for diminished control from applications targeted towards the early growth stage may be due to less purple nutsedge foliage compared to applications made at the larger size resulting in less herbicide uptake

In the non cropping study, glyphosate at 0 57 kg/ha generally resulted in less purple nutsedge control than glyphosate at 1 14 kg/ha, with the exception of 1999 when sequential applications targeted towards the latter growth stage provided good control regardless of glyphosate rates (Tables 2 1 and 2 2) Glyphosate at 0 86 kg/ha generally resulted in control similar to either 0 57 or 1 14 kg/ha in each year 8 WAIT (Table 2.2).

Glyphosate-Tolerant Cotton Experiment

There was a treatment by year interaction ($P \leq 0.05$) for purple nutsedge control 4 WAIT which prevented pooling across year In 1997, purple nutsedge control 4 WAIT in cotton increased by 28% when glyphosate was applied at 0 57 kg/ha to the smaller nutsedge compared with control obtained when application was targeted towards the larger nutsedge (Table 2 3) There was no difference ($P \geq 0.05$) in control between glyphosate at 0 57 kg/ha applied to purple nutsedge at the smaller size or glyphosate at 0 86 or 1 14 kg/ha applied to either purple nutsedge size Purple nutsedge growth stage did not influence control in 1998 Glyphosate at 0 57 kg/ha controlled purple nutsedge 52% 4 WAIT in 1998, and was increased to 74% with glyphosate at 0 86 or 1 14 kg/ha

(data not shown) Because excessive rains in 1999 resulted in flooded conditions prior to the early growth stage application with glyphosate, purple nutsedge control was less than that observed in 1997 and 1998 Nonetheless, the most effective glyphosate rate for purple nutsedge control when application was delayed was 1 14 kg/ha (Table 2.3).

There was a treatment by year interaction ($P \leq 0.05$) for purple nutsedge control 8 WAIT which prevented pooling. In 1997, delaying application to purple nutsedge 20 to 38 cm in height resulted in <60% control with a single POST treatment of glyphosate at 0.37 or 0 86 kg/ha (Table 2.4) Within each of the application sequences targeted towards the earlier growth stage, glyphosate rate did not influence control in 1997 Sequential treatments were not beneficial when initial application was delayed to the latter growth stage in 1997

There was not a treatment by application timing interaction for purple nutsedge control 8 WAIT in 1998 and data was pooled across purple nutsedge size at application Glyphosate at 0 57 kg/ha resulted in 75 and 86% control when applied to purple nutsedge 8 to 15 cm and 20 to 38 cm in height, respectively (data not shown). When glyphosate rate was increased to ≥0.86 kg/ha, purple nutsedge control 8 WAIT averaged 86 and 92% when applied to purple nutsedge 8 to 15 cm and 20 to 38 cm in height, respectively (data not shown)

In 1999, glyphosate rate, purple nutsedge size and application treatment was significant ($P \leq 0.05$) for purple nutsedge control 8 WAIT in cotton At the earlier growth stage <50% control was observed with a single glyphosate application regardless of rate, possibly due to the early-season flooded conditions in 1999 (Table 2 4) Nonetheless

control was increased to >70% when sequential treatments of glyphosate at either 0.86 or 1.14 kg/ha were applied. When applied to larger nutsedge, a single treatment of glyphosate at 0.57 kg/ha resulted in <50% control 8 WAIT, and was increased to 85% control when glyphosate was applied at 1.14 kg/ha. Greater than 90% control was observed at all rates when applied to larger nutsedge when a sequential application was utilized with the exception of a POST directed-spray at 0.57 kg/ha (Table 2.4)

Cotton growth in the untreated check in 1997 was reduced by 20 and 30% from purple nutsedge competition at the 4 and 8 WAIT respectively, with a cotton lint yield of 210 kg/ha (data not shown). In 1998 purple nutsedge competition had more adverse affect on cotton growth than 1997 early season due to less rainfall. Cotton was stunted 34 and 45% 4 and 8 WAIT, respectively with a seed yield of 301 kg/ha (data not shown). Similar stunting in the untreated check was observed in 1999, but resulted in a seed yield of 498 kg/ha which was higher presumably due to greater rainfall early-season (data not shown).

Cotton growth was not affected by purple nutsedge competition in 1997 in any glyphosate treated plot (data not shown). In 1998, early season cotton growth was not affected by glyphosate rate. However, treatments targeted towards smaller purple nutsedge resulted in <5% early-season cotton stunting, compared to a 27% overall reduction in cotton growth from competition when applications were delayed until the larger nutsedge (data not shown). In 1999 purple nutsedge height at application did not influence cotton growth from competition and data was pooled across both heights. Early season cotton growth was reduced by 25% with glyphosate at 1.14 kg/ha, and was

increased to an average of 32% growth reduction with glyphosate at 0.57 and 0.86 kg/ha presumably due to less purple nutsedge control at the lower glyphosate rates (data not shown). Cotton stunting in 1999, despite adequate rainfall, may be attributed to a greater purple nutsedge population than 1998 and 1997. In 1999, the average purple nutsedge population was 300 plants per m^2 following planting, compared to 100 to 150 plants per m^2 in 1997 and 1998.

Treating purple nutsedge in cotton with glyphosate POST increased yield compared to the untreated check. However, even though purple nutsedge size at application and number of applications may have affected purple nutsedge control and cotton stunting, these factors did not influence cotton yield. Seed cotton yield was 210, 301, and 458 kg/ha in the untreated check in 1997, 1998, and 1999 (data not shown). Average cotton seed yield for glyphosate treatments was 1407, 756, and 2024 kg/ha in 1997, 1998, and 1999 (data not shown).

Purple nutsedge control in these studies was influenced by glyphosate rate, purple nutsedge growth stage, and application timing. Furthermore, similar levels of purple nutsedge control were observed in fallow and glyphosate-tolerant cotton. In the fallow experiment, sequential treatments were beneficial, and when ≥ 0.86 kg/ha of glyphosate were applied at least 84% control was observed. Other investigators have reported that sequential applications of glyphosate were more beneficial in reducing stands of purple nutsedge than a single treatment (Zandstra et al. 1974). In 1997 when good season long growing conditions existed, there was no difference in control between purple nutsedge growth stages, but a delay in application was beneficial in 1998 and 1999.

Despite no yield differences in the cotton experiment between glyphosate treatments in each year, glyphosate should still be targeted towards the earlier growth stage of 8 to 15 cm tall. Delaying glyphosate application in the cotton studies to 20 to 30 cm tall purple nutsedge resulted in significantly stunted cotton due to lack of rain fall in 1998. Furthermore, if it was not for an active hurricane season in the fall of 1998, there would have likely been a substantial yield advantage for glyphosate applications targeted towards the earlier growth stage. Therefore, control measures for purple nutsedge should be targeted early in the season with at least 0.86 kg/ha of glyphosate to give cotton the greatest competitive advantage.

Table 2 1 The effect of glyphosate rate and purple nutsedge height on purple nutsedge control 4 weeks after initial treatment in fallow, Jay, FL [1]

Glyphosate	Purple nutsedge height[2]	1997	1998	1999
kg/ha	— cm —		% control	
0 57	8 to 15	73 b	60 a	47 d
0 57	20 to 38	66 c	53 b	44 d
0 86	8 to 15	73 b	63 a	61 c
0 86	20 to 38	73 b	60 a	68 b
1 14	8 to 15	78 a	65 a	69 b
1 14	20 to 38	74 ab	60 a	84 a

[1] Means followed by the same letter within a column are not significantly different according to Fisher s Protected LSD test at P = 0 05

[2] Purple nutsedge height at application

Table 2 2 The effect of glyphosate rate, number of applications, and purple nutsedge height on control 8 weeks after initial treatment in fallow Jay FL [1]

Glyphosate	Purple nutsedge height[2]	Application[3]	1997	1998	1999
kg/ha	— cm —			% control	
0.57	8 to 15	single	74 de	50 cd	40 f
0 57	20 to 30	single	72 e	50 cd	71 bd
0 57	8 to 15	sequential	84 bc	55 cd	59 de
0.57	20 to 30	sequential	86 b	63 bc	90 a
0 86	8 to 15	single	74 de	45 d	35 e
0.86	20 to 30	single	70 e	60 bcd	71 bd
0 86	8 to 15	sequential	88 ab	48 cd	61 de
0 86	20 to 30	sequential	89 ab	85 a	94 a
1 14	8 to 15	single	76 de	45 d	65 de
1 14	20 to 30	single	79 cd	74 ab	83 ab
1 14	8 to 15	sequential	90 ab	75 ab	73 b
1 14	20 to 30	sequential	93 a	89 a	94 a

[1] Means followed by the same letter within a column are not significantly different according to Fisher s Protected LSD test at P = 0 05

[2] Purple nutsedge height at initial application

[3] Sequential application 4 week after initial treatment.

Table 2 3 The effect of glyphosate rate and purple nutsedge size on purple nutsedge control and cotton stunting 4 weeks after treatment in glyphosate-tolerant cotton, Jay, FL.[1]

Glyphosate	Purple nutsedge height[2]	1997	1999
kg/ha	— cm —	% control	
0 57	8 to 15	76 a	45 d
0 57	20 to 38	59 b	36 e
0 86	8 to 15	78 a	54 c
0 86	20 to 38	76 a	60 b
1 14	8 to 15	79 a	56 bc
1 14	20 to 38	79 a	85 a

[1] Means followed by the same letter within a column are not significantly different according to Fisher s Protected LSD test at P 0 05

[2] Purple nutsedge height at application

Table 2 4 The effect of glyphosate rate application treatment, and purple nutsedge size on purple nutsedge control in cotton 8 weeks after initial treatment in glyphosate-tolerant cotton Jay FL [1]

Glyphosate	Purple nutsedge height[2]	Application[3]	1997	1998
kg/ha	— cm —		— % control —	
0 57	8 to 15	POST	74 e	43 i
0 57	20 to 38	POST	53 e	49 hi
0 57	8 to 15	POST (fb) POST	88 ab	60 g
0 57	20 to 38	POST (fb) POST	73 cd	90 abc
0 57	8 to 15	POST (fb) PDS	81 abc	55 gh
0 57	20 to 38	POST (fb) PDS	61 de	71 f
0 86	8 to 15	POST	73 cd	49 hi
0 86	20 to 38	POST	53 e	74 f
0 86	8 to 15	POST (fb) POST	92 a	76 ef
0 86	20 to 38	POST (fb) POST	86 ab	95 a
0 86	8 to 15	POST (fb) PDS	89 ab	73 f
0 86	20 to 38	POST (fb) POS	78 bc	91 ab
1 14	8 to 15	POST	74 c	46 i
1 14	20 to 38	POST	80 abc	85 bcd
1 14	8 to 15	POST (fb) POST	89 ab	83 cde
1 14	20 to 38	POST (fb) POST	90 ab	95 a
1 14	8 to 15	POST (fb) PDS	90 ab	79 def
1 14	20 to 38	POST (fb) POS	88 ab	95 a

[1] Entire study received pendimethalin pre plant incorporated at 0 86 kg/ha plus fluometuron pre-emergence at 1 7 kg/ha for annual grass and broadleaf weed control Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD test at P = 0 05

[2] Purple nutsedge height at initial application

[3] Application treatment postemergence (POST) POST followed by (fb) POST 4 week after initial treatment, POST (fb) post-directed spray (PDS) 4 week after initial treatment.

CHAPTER III
EFFECT OF GLYPHOSATE AND MSMA APPLICATION TIMING ON FRUITING CHARACTERISTICS OF GLYPHOSATE TOLERANT COTTON (*GOSSYPIUM HIRSUTUM*)

Introduction

Weeds are critical pests in cotton production that deprive the crop of water, nutrients, light, and space and adversely affect both yield and lint quality. Though it is grown as an annual crop, cotton is actually a perennial plant with slow early-season growth compared to other crops such as corn and soybeans. Therefore, weed control is critical even 9 to 10 weeks after planting for cotton to become competitive and ensure normal development (Buchanan and Burns 1970).

Weed spectrums in cotton are diverse and include grasses, broadleaves, and sedges. Observations by weed scientists in Florida, Georgia, and Alabama reported that *Digitaria, Panicum, Ipomoea, Richardia, Senna, Sida, Amaranthus, Xanthium, Desmodium, Cyperus, Melochia, Euphorbia, Eleusine, Acanthospermum*, and *Cassia* spp. are common and troublesome to control in southeastern U.S. cotton production (Dowler 1998). Therefore, it is not surprising that typical weed management programs in cotton rely on cultivation and herbicides that are applied to the soil: postemergence (POST) over-the-top, and POST-directed to control various weeds that may emerge early in the growing season (Buchanan 1992, Jordan et al. 1997).

Growers still rely heavily on POST herbicide applications despite the use of dinitroaniline herbicides such as pendimethalin [*N* (1-ethylpropyl)-3 4-dimethyl-2 6-dinitrobenzenamine] for annual grasses and small seeded broadleaf weeds, and pre emergence herbicides such as fluometuron [*N,N*-dimethyl-*N'*-[3-(trifluoromethyl)phenyl)]urea] for broadleaf weeds (Wilcut et al 1997) The development of glyphosate-tolerant cotton has allowed glyphosate to be an alternative to traditional POST herbicides such as MSMA [monosodium methanearsonate] grammicides, and pyrithiobac [2-chloro-6-[(4,6-dimethoxy 2 pyrimidinyl)thio]benzoic acid sodium salt] (Culpepper and York 1998) Glyphosate[1] [*N*-(phosphonylmethyl)glycine] is a non-selective herbicide that can be applied POST over the-top to glyphosate-tolerant cotton up to the 4-leaf stage and is effective on many weedy plant species While glyphosate-tolerant cotton is not significantly affected by glyphosate treatment prior to 4-leaf stage (Jones and Snipes 1999) the effect of subsequent glyphosate applications on cotton growth and development is not fully known

Cotton is indeterminate with vegetative growth continuing after anthesis Initial fruit appears at the base of the plant, and fruiting continues throughout the growing season at regular intervals Fruiting continues until the occurrence of a white flower within five nodes of the terminal apex when the plant is considered to "cutout" (Bourland et al 1992). Cutout can be a benchmark for season end management decisions such as termination of insecticide applications and timing of defoliation Fruiting

[1]Roundup Ultra supplemental label for cotton with the Roundup Ready® gene Monsanto Company St Louis MO 63167

intervals occur about every 3 days throughout the season for vertical sites 6 days for horizontal sites, and may ultimately produce 20 to 24 vertical main stem nodes in a growing season (Jenkins et al 1990) Constable (1991) reported that bolls at inner positions on sympodial (fruiting) branches located on mainstem nodes 7 to 13 contribute most to yield Fruit produced from the first position from the mainstem axis are generally larger, and have higher retention (presumably through competition) than positions further from the main axis When the first position is occupied, boll weight of the second position may be reduced by 25%, and the third by about 30%

Investigators have reported the effective use of plant mapping techniques as an instrument to quantify the effect of herbicides and plant growth regulators on the growth and performance of cotton (Boone et al 1995 Bourland and Watson 1990 Guthrie and York 1989 Reddy et al 1990 Snipes and Byrd 1994) Simple analysis of cotton fruiting structures is difficult because fruit sites are interdependent. COTMAP (Bourland and Watson 1990) is a plant mapping technique that provides collective methodology for analysis of boll production from positions closest to the main axis. The COTMAP method provides detailed information on the prime fruiting sites (position one and position two) on sympodial (fruiting) cotton branches (Bourland and Watson 1990 Figure 3 1)

The advent of glyphosate-tolerant cotton provides a unique option for weed management Research is needed to determine the optimal glyphosate timing for weed control With this new technology, however optimal timing of glyphosate may not be conducive to optimal cotton growth The objectives of these experiments were to

determine the effects of application timing on weed control and to evaluate the effect of the herbicide on cotton fruiting structures and yield. Furthermore, since many farmers still rely on MSMA herbicide for mid-season weed control (Jordan et al. 1997), an additional objective was to evaluate the widely used POST herbicide MSMA on cotton fruit development and yield in comparison to glyphosate.

Materials and Methods

Field experiments were conducted in 1997, 1998, and 1999 at the University of Florida's West Florida Research and Education Center located in Jay. The soil was Red Bay fine sandy loam with 2.2% organic matter, 69% sand, 16% silt, and 15% clay (siliceous, thermic Rhodic Paleudult). Cotton, Deltapine 5415RR, was planted the first week of May in each year. Typical production practices such as fertilization, insect management, and cotton defoliation were followed for Florida's panhandle according to Sprenkel (1996). The entire test-site was treated with pendimethalin at 0.86 kg/ha pre-plant incorporated with a roto-tiller and fluometuron at 1.7 kg/ha pre-emergence for early-season annual grass and broadleaf weed control.

Postemergence herbicide treatments included glyphosate applied at: 4-leaf postemergence over-the-top (POST), 6-leaf POST, 8-leaf POST, 10-leaf POST, 12-leaf POST; 4-leaf POST followed by 6-leaf POST; 4-leaf POST followed by 8-leaf POST, 4-leaf POST followed by 10-leaf POST; 4-leaf POST followed by 6-leaf POST-directed, 4-leaf POST followed by 8-leaf POST-directed, 4-leaf POST followed by 10-leaf POST-directed, and 4-leaf POST followed by 12-leaf POST-directed, and MSMA at 1.7 kg/ha applied at: 4-leaf POST, 6-leaf POST, 8-leaf POS, 10-leaf POST, and 12-leaf POST. An

untreated check was included for comparison A split plot treatment arrangement was utilized with weed free vs. weedy as main plots and herbicide treatments as sub-plots Weeds were manually removed from weed-free plots so that herbicide effect on crop reproductive characteristics and yield could be measured in the absence of weed interference

Weed spectrums consisted of sicklepod (*Senna obtusifolia* L.) redweed (*Melochia corchorifolia* L.) pitted morningglory (*Ipomoea lacunosa* L.) and Florida beggarweed (*Desmodium tortuosum* (Sw) DC) (Table 3 1) Visual estimates of percent weed control in weedy plots were made approximately 75 (mid season) and 105 days (late-season) after planting using a scale of 0 to 100 where 0 = no control and 100 = complete control In the weed free plots following defoliation and prior to harvest, 10 plants per plot were randomly chosen and cotton fruit were mapped from the center two rows according to the COTMAP technique (Bourland and Watson 1990) Plant mapping data collected included total number of mainstem nodes per plant (TN), number of monopodium per plant (M), position one percent boll retention (BR1) position two percent boll retention (BR2) and early boll retention defined as percent boll retention on first and second positions on lowest five sympodia. At season s end following plant mapping, the center two rows of the four-plot (76 cm spacing by 7 6 m) were harvested with commercial equipment

Treatments were replicated four times and the experiment was repeated for three years Homogeneity of variance was evaluated prior to data analysis and data were subjected to ANOVA to test for treatment effects and possible interactions Means were

separated using the General Linear Model procedure (SAS institute 1987), with Fischer's Protected LSD test set at P = 0 05 in the weed control data and P = 0 10 in the plant mapping data.

Results and Discussion

Weed Control

Pendimethalin PPI followed by fluometuron failed to control sicklepod, redweed, and pitted morningglory There was a treatment by year interaction (P ≤ 0 05) for sicklepod control which prevented pooling Sicklepod was more responsive to herbicide treatments in 1999 than 1998 or 1997 possibly due to better growing conditions from high early season rainfall in 1999 (Table 3 2) Woldecker and Wyse observed similar results and reported that common milkweed plants with adequate water absorbed and translocated more glyphosate than moisture stressed plants (1985) Nonetheless, similar overall trends of sicklepod control from application timings were observed in each year

Sicklepod was controlled at least 90% both mid and late-season with glyphosate at the 4 and 6 leaf timing (Table 3 1) Sicklepod control with single glyphosate applications beyond 8 leaf were highly variable and ranged between 38 and 79% depending on year (Table 3.2) Sequential glyphosate applications, regardless of whether the second treatment was applied over-the-top or POST-directed resulted in at least 90% sicklepod control Single applications of MSMA were less effective for sicklepod control than single applications of glyphosate Wilcut et al (1997) reported that including fluometuron in the MSMA tank mix controlled sicklepod and morningglories better than

MSMA alone Similar to the glyphosate treatments MSMA controlled sicklepod better at the earlier timings (4 or 6 leaf cotton stage) than when delayed (Table 3.2)

A treatment by year interaction ($P \geq 0.05$) was not observed for redweed and pitted morningglory and data were pooled over years Glyphosate controlled redweed at least 90% both mid- and late season provided that applications were made at the 4, 6, or 8-leaf cotton stage (Table 3 2) All sequential glyphosate applications following the 4-leaf cotton stage controlled redweed. MSMA was ineffective on redweed and resulted in ≤60% control (Table 3 2)

Glyphosate was most effective on pitted morningglory at the 4-leaf cotton stage and provided 91% control mid-season (Table 3 2) However, for late-season pitted morningglory control, sequential applications were necessary since single applications of glyphosate ranged from 48 to 70% control Culpepper and York (1998) reported a single early POST application of glyphosate controlled pitted morningglory only 50%, whereas including a sequential POST-directed application of glyphosate increased control to 93% There were no differences among the sequential glyphosate treatments for pitted morningglory control mid-season, but by late-season the 12-leaf POST-directed application was more effective than 12-leaf over the top MSMA controlled pitted morningglory better at the 4-leaf cotton timing and a delay in application resulted in <70% control (Table 3 2)

There was no treatment effect ($P \geq 0.05$) for Florida beggarweed control Glyphosate and MSMA both controlled Florida beggarweed regardless of application

timing (data not shown). Johnson et al. (1997) has also reported that MSMA is very effective on Florida beggarweed, even on large mid-season plants.

There was a treatment by year interaction ($P \leq 0.05$) for seed cotton yield on weedy plots and data were presented separately by year (Table 3.3). Yield in 1997 and 1999 were similar, however, fall storms in 1998 adversely affected yield throughout Florida's panhandle. There were no yield differences in weedy plots between single glyphosate applications at 4, 6 or 8-leaf cotton in any year. Applications delayed beyond 8-leaf cotton resulted in less yield due to either early season weed competition or less glyphosate tolerance. Even though there were no differences in weed control among glyphosate at 4-leaf POST followed by 6-leaf POST or 4-leaf POST followed by 10 leaf POST, the latter timing resulted in a 15% yield reduction compared with the earlier timing in 1997 and 1998. There were no differences in yield among weedy plots between sequential POST glyphosate treatments in 1997 or 1998 provided they were POST directed. There were no yield differences among weedy plots in 1999 between single POST glyphosate treatments at 4, 6, or 8-leaf cotton or any sequential POST application.

Applications of MSMA timed to 4, 6, and 8 leaf cotton were not different in yield from the weed-free untreated check in any year (Table 3.3). In 1998 and 1999 there was not a yield reduction with MSMA in weedy plots until applications were made at the 12 leaf cotton stage (Table 3.3). In 1997 and 1999, all MSMA treatments within weedy plots yielded less than glyphosate applied at 4, 6, or 8 leaf cotton. Similar yields in 1998 within weedy plots were observed between glyphosate and MSMA at each application timing.

Glyphosate was most effective in controlling sicklepod, redweed, and pitted morningglory at either the 4 or 6 leaf cotton stage compared to later applications of glyphosate (Table 3 2) Single applications beyond the 6-leaf timing generally resulted in less effective control Furthermore sequential glyphosate applications increased control late season compared to a single application and resulted in better yields (Tables 3 2 and 3 3) The optimum timing for season long control with glyphosate of the entire weed spectrum without a yield loss compared to the weed free untreated check was 4 leaf POST followed by 8-leaf either over-the-top or POST-directed, or 4 leaf POST followed by 10 or 12 leaf POST-directed Glyphosate at 4 leaf followed by 10 or 12-leaf POST resulted in similar weed control in each year but there was a yield reduction with the late POST over the-top applications compared to POST-directed presumably due to increased fruit loss

Plant Mapping

There was a treatment by year interaction ($P \leq 0.10$) for most plant growth parameters and yield which prevented pooling. Therefore, data is presented separately by year

Herbicide treatment or application timing did not influence the total number of mainstem nodes per plant in any year (Tables 3 4, 3 5, and 3 6) The number of monopodium branches generally declined in 1997 as application timing with glyphosate was delayed beyond the 4-leaf cotton stage or sequential applications were included in the treatment (Table 3 4) There were no differences between herbicides and application timing for the number of monopodium branches in 1998 and 1999 (Tables 3 5 and 3 6)

Single glyphosate applications at 4 and 6-leaf POST or MSMA at 4, 6, 8 and 10 leaf cotton did not adversely affect first position sympodia boll retention compared to the untreated check in 1997 (Table 3 4). When herbicide application was delayed beyond these cotton leaf stages first position boll retention was reduced overall by 25% and 20% with glyphosate and MSMA respectively (Table 3 4). There was no difference between a single glyphosate application at the 4-leaf cotton stage and 4 leaf followed by 6-leaf POST or POST directed However, sequential applications of glyphosate after the 6-leaf cotton stage adversely affected first position boll retention regardless of over-the-top or POST-directed in 1997 (Table 3 4)

There was no treatment affect ($P \geq 0.10$) for second position sympodia boll retention in 1997 (Table 3 4) Early boll retention (first and second positions on lowest five sympodia) was adversely affected when glyphosate or MSMA was applied beyond the 6-leaf cotton stage, independent of a single or sequential application Even though glyphosate and MSMA did affect fruiting patterns and distribution when applied at the 8 and 10-leaf cotton stage in 1997 there was not a reduction in yield compared with the weed-free untreated check among either herbicide until applied at 10 or 12-leaf (Table 3 4)

There was no treatment effect ($P \geq 0.10$) for first and second boll retention in 1998 (Table 3 5) Early boll retention on the first five sympodia branches was adversely affected by all glyphosate and MSMA treatments applied to 12-leaf POST over the top or POST-directed in 1998 (Table 3 5) However despite fruiting difference from

application timings, there were no differences in yield between any treatment among weed free plots in 1998

First position boll retention was adversely affected in 1999 when glyphosate was applied POST over-the-top at 12-leaf cotton, and was unaffected by 4-leaf POST followed by 12-leaf POST-directed (Table 3.6). There was no treatment effect ($P \geq 0.10$) for second position boll retention or early boll retention in 1999. There were no differences in yield between glyphosate treatments among weed free plots in 1999 however MSMA applied at the 12 leaf cotton stage did result in a 20% yield reduction compared to the weed-free untreated check.

These data support the work of Jones and Snipes (1999) who reported that the reproductive development of glyphosate tolerant cotton is sensitive to delayed applications of glyphosate. However Jones and Snipes (1999) only evaluated the effects up to the six leaf cotton stage with cotton varieties Deltapine 9683 RR®, Deltapine 9685RR™ Deltapine 9687RR™ and Coker 312RR in Stoneville, Mississippi. In Florida, topical applications of glyphosate did not adversely affect growth parameters of cotton variety Deltapine 5415 RR when timed at the 4 leaf or 6 leaf cotton stage in 1997 or when applications were delayed up to 10-leaf in 1998 and 1999.

Several studies have cited that first and second position fruit retention are highly correlated to yield (Wells and Meredith 1984, Constable 1991). However investigators have also reported that cotton is somewhat resilient. Cotton plants with early fruit removed have been known to compensate for early fruit loss with increased flowering and later season fruit retention (Kletter and Wallach 1982, Kennedy et al. 1986). Jones and

Snipes (1999) found reductions in early-season fruit retention from over-the top applications of glyphosate in glyphosate-tolerant cotton however, considerable compensation following early-season fruit loss was observed and no yield loss was recorded

These experiments investigated over-the top applications up to the 12 leaf stage to gain better knowledge of tolerance and potential fruit loss in late-season salvage applications with glyphosate and MSMA Generally, cotton 'DP 5415RR was more tolerant to late applications of glyphosate than MSMA, while generally providing better overall weed control Glyphosate timed at the 12-leaf stage resulted in a 19 and 14% yield loss compared to the weed-free untreated check in 1997 (Table 3 4) and 1999 (Table 3 6) respectively, whereas MSMA timed at 12-leaf stage reduced yield by 58% and 36%

These data illustrate that glyphosate-tolerant cotton provides an effective alternative to traditional weed control programs Current labeling restrictions allow over the-top applications of glyphosate up to the 4-leaf stage In these studies, glyphosate did not affect cotton fruit development or yield when following current labeling restrictions and effectively controlled a typical weed spectrum in Florida s panhandle with an over-the top application at the 4 leaf cotton stage followed by a directed POST application at either the 8 or 10 leaf cotton.

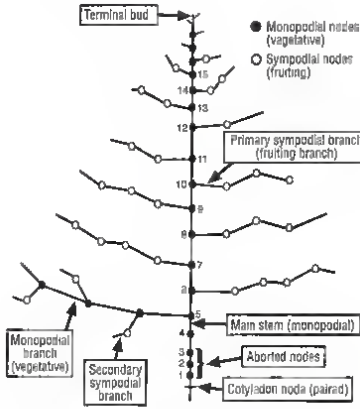

Figure 3 1 Plant diagram to illustrate cotton fruit development (Beurland and Watson 1990)

Table 3.1 Average broadleaf weed leaf size and height at each glyphosate and MSMA application timing in cotton DP 5415RR Jay FL 1997 1998 and 1999

Cotton application timing		Sicklepod		Redweed		Pitted morningglory	Florida beggarweed	
Leaf	Height	Leaf	Height	Leaf	Height	Width	Leaf	Height
no	cm	no	cm	no	cm	cm	no	cm
4	13	4	15	2	7	15	4	10
6	23	8	30	4	15	30	6	15
8	50	10	40	8	25	50	8	25
10	55	12	60	12	40	75	14	40
12	60	17	90	20	70	80	16	75

Table 3.2 The effect of glyphosate and MSMA application timing on broadleaf weed control in cotton DP 5415RR[1] Jay FL

			Suckleped									
			1997		1998		1999					
									Redweed[2]		Pitted morningglory[2]	
	Herbicide[1]	Timing	Mid	Late	Mid	Late	Mid	Late	Mid	Late	Mid	Late
			%									
1	Gly	4 lf POST	99	98	96	99	97	96	99	98	91	70
2	Gly	6 lf POST	93	90	93	99	98	93	93	94	60	48
3	Gly	8 lf POST	74	84	86	99	98	97	90	91	66	70
4	Gly	10 lf POST	51	38	63	79	77	79	85	60	68	70
5	Gly	12 lf POST	53	48	40	59	68	71	60	60	45	70
6	Gly	4 lf POST (fb) 6 lf POST	96	99	95	99	99	99	98	99	93	90
7	Gly	4 lf POST (fb) 8 lf POST	98	99	95	99	99	99	99	99	95	91
8	Gly	4 lf POST (fb) 10 lf POST	99	99	94	99	99	99	99	99	93	—
9	Gly	4 lf POST (fb) 12 lf POST	—	—	93	96	99	99	99	99	85	—
10	Gly	4 lf POST (fb) 6 lf PDS	96	99	94	99	99	99	99	99	94	91
11	Gly	4 lf POST (fb) 8 lf PDS	99	99	93	99	99	99	99	99	94	93
12	Gly	4 lf POST (fb) 10 lf PDS	99	99	93	99	99	99	99	99	90	93
13	Gly	4 lf POST (fb) 12 lf PDS	—	—	91	99	99	99	99	99	90	93
14	MSMA	4 lf POST	74	68	76	81	80	65	40	53	80	81
15	MSMA	6 lf POST	69	71	63	64	80	58	55	60	68	53
16	MSMA	8 lf POST	55	46	50	55	58	38	45	60	65	65
17	MSMA	10 lf POST	55	43	40	23	55	30	65	55	43	43
18	MSMA	12 lf POST	50	53	23	23	64	49	55	55	23	43
LSD (0.10)			9	8	9	7	10	11	9	7	13	19

[1] Glyphosate rate = 0.85 kg/ha MSMA rate = 1.7 kg/ha, lf = cotton leaf stage above cotyledon, POST = postemergence over-the-top, PDS = post-directed spray Weed control ratings Mid = 75 days after planting, Late = 105 days after planting

[2] Data pooled across year

Table 3 3 Seed cotton yield with postemergence herbicide treatments on weedy plots, Jay FL

Herbicide[1]	Postemergence timing	Seed cotton yield		
		1997	1998	1999
		kg/ha		
1 Gly	4 lf POST	2700	1800	2900
2 Gly	6 lf POST	2600	1400	3200
3 Gly	8 lf POST	2400	1700	3200
4 Gly	10 lf POST	900	200	2500
5 Gly	12 lf POST	0	200	2400
6 Gly	4 lf POST (fb) 6 lf POST	3400	2300	3000
7 Gly	4 lf POST (fb) 8 lf POST	3000	2200	2900
8 Gly	4 lf POST (fb) 10 lf POST	2400	1900	2800
9 Gly	4 lf POST (fb) 12 lf POST	—	1500	2800
10 Gly	4 lf POST (fb) 6 lf PDS	2900	2000	2900
11 Gly	4 lf POST (fb) 8 lf PDS	3000	2000	2900
12 Gly	4 lf POST (fb) 10 lf PDS	2900	2100	3100
13 Gly	4 lf POST (fb) 12 lf PDS	—	2000	2900
14 MSMA	4 lf POST	1600	1400	2200
15 MSMA	6 lf POST	1900	1700	2400
16 MSMA	8 lf POST	1200	1400	2000
17 MSMA	10 lf POST	200	1600	1800
18 MSMA	12 lf POST	0	0	600
19 Untreated	—	0	0	300
LSD (0.10)		500	300	500

[1] Gly = glyphosate rate at 0.85 kg/ha, MSMA at 1.7 kg/ha, lf = cotton leaf stage above cotyledon, POST = postemergence over the-top, PDS = post-directed spray

Table 3 4 The effect of glyphosate and MSMA application timing on fruiting characteristics and yield of cotton 'DP 5415RR' in weed free plots, Jay FL 1997

Herbicide[2]	Timing	Fruiting characteristics[1]					Seed yield
		TN	M	BR1	BR2	EBR	
		— no. —			— % —		kg/ha
1 Gly	4 lf POST	17	0 6	48	20	32	2600
2 Gly	6 lf POST	17	0 4	55	22	37	2600
3 Gly	8 lf POST	17	0.3	36	20	21	2500
4 Gly	10 lf POST	17	0 1	40	23	21	2300
5 Gly	12 lf POST	17	0 1	37	20	16	2100
6 Gly	4 lf POST (fb) 6 lf POST	18	0.2	42	19	23	2800
7 Gly	4 lf POST (fb) 8 lf POST	17	0 1	33	23	17	2800
8 Gly	4 lf POST (fb) 10 lf POST	17	0.2	34	22	17	2700
9 Gly	4 lf POST (fb) 12 lf POST						
10 Gly	4 lf POST (fb) 6 lf PDS	17	0.3	41	22	25	2900
11 Gly	4 lf POST (fb) 8 lf PDS	17	0.3	33	22	18	2900
12 Gly	4 lf POST (fb) 10 lf PDS	18	0.3	34	25	18	2800
13 Gly	4 lf POST (fb) 12 lf PDS						
14 MSMA	4 lf POST	17	0.3	39	22	24	2600
15 MSMA	6 lf POST	17	0 2	39	21	24	2200
16 MSMA	8 lf POST	17	0 1	40	23	20	2300
17 MSMA	10 lf POST	17	0 3	39	21	19	1900
18 MSMA	12 lf POST	18	0 2	31	19	15	1100
19 Untreated	—	17	0 6	46	19	32	2600
LSD (0 10)		NS	0 3	9	NS	11	500

TN = number of mainstem nodes per plant, M = number of monopodium per plant, BR1 = boll retention position 1, BR2 = boll retention position 2, EBR = early boll retention defined as first and second positions on lowest five sympodia.

[2]Gly = glyphosate at 0 85 kg/ha, MSMA at 1 7 kg/ha, lf = cotton leaf stage above cotyledon, POT = postemergence over the top, PDS = post-directed spray

Table 3.5 The effect of glyphosate and MSMA application timing on fruiting characteristics and yield of cotton 'DP 5415RR' in weed-free plots, Jay FL 1998

	Herbicide[2]	Timing	Fruiting characteristics[1]					Seed yield
			TN	M	BR1	BR2	EBR	
			no		%			kg/ha
1	Gly	4 lf POST	18	2.7	25	19	18	2100
2	Gly	6 lf POST	18	2.2	33	27	16	2100
3	Gly	8 lf POST	18	2.5	29	18	12	2200
4	Gly	10 lf POST	18	2.8	33	26	12	2300
5	Gly	12 lf POST	19	2.2	27	21	9	2200
6	Gly	4 lf POST (fb) 6 lf POST	18	2.5	25	20	12	2100
7	Gly	4 lf POST (fb) 8 lf POST	17	2.7	25	21	16	2100
8	Gly	4 lf POST (fb) 10 lf POST	18	2.4	30	24	12	2200
9	Gly	4 lf POST (fb) 12 lf POST	19	2.2	24	16	6	2100
10	Gly	4 lf POST (fb) 6 lf PDS	19	2.2	23	18	12	2100
11	Gly	4 lf POST (fb) 8 lf PDS	18	2.2	25	19	9	2100
12	Gly	4 lf POST (fb) 10 lf PDS	18	2.7	24	20	7	2100
13	Gly	4 lf POST (fb) 12 lf PDS	19	2.4	22	18	7	2000
14	MSMA	4 lf POST	18	2.6	25	17	9	2100
15	MSMA	6 lf POST	18	3.1	21	19	11	2000
16	MSMA	8 lf POST	18	2.8	21	19	5	2100
17	MSMA	10 lf POST	18	2.7	28	23	15	1900
18	MSMA	12 lf POST	19	2.2	22	18	8	1800
19	Untreated	—	19	2.4	26	21	18	1900
LSD (0.10)			NS	NS	NS	NS	7	NS

[1] TN = number of mainstem nodes per plant, M = number of monopodium per plant, BR1 = boll retention position 1, BR2 = boll retention position 2, EBR = early boll retention defined as first and second positions on lowest five sympodia.

[2] Gly = glyphosate at 0.85 kg/ha, MSMA at 1.7 kg/ha, lf = cotton leaf stage above cotyledon, POT = postemergence over the-top, PDS = post-directed spray

Table 3.6 The effect of glyphosate and MSMA application timing on fruiting characteristics and yield of cotton DP 5415RR in weed-free plots, Jay FL 1999

Herbicide[2]	Timing	Fruiting characteristics[1]					Seed yield
		TN	M	BR1	BR2	EBR	
		— no —		——— % ———			kg/ha
1 Gly	4 lf POST	18	1.4	52	22	50	2800
2 Gly	6 lf POST	18	1.0	52	22	46	2800
3 Gly	8 lf POST	18	1.3	48	23	46	2800
4 Gly	10 lf POST	18	1.2	47	23	46	2500
5 Gly	12 lf POST	19	1.5	40	26	38	2400
6 Gly	4 lf POST (fb) 6 lf POST	19	1.5	48	26	45	2400
7 Gly	4 lf POST (fb) 8 lf POST	19	1.4	51	25	42	2600
8 Gly	4 lf POST (fb) 10 lf POST	19	2.0	46	23	38	2500
9 Gly	4 lf POST (fb) 12 lf POST	19	2.0	37	22	36	2400
10 Gly	4 lf POST (fb) 6 lf PDS	18	1.7	48	23	42	2500
11 Gly	4 lf POST (fb) 8 lf PDS	19	1.5	44	23	40	2700
12 Gly	4 lf POST (fb) 10 lf PDS	19	2.0	49	22	48	2700
13 Gly	4 lf POST (fb) 12 lf PDS	18	2.1	51	22	45	2700
14 MSMA	4 lf POST	20	1.6	46	22	36	2100
15 MSMA	6 lf POST	19	1.2	47	21	38	2200
16 MSMA	8 lf POST	18	1.2	48	22	36	2500
17 MSMA	10 lf POST	19	1.8	46	18	40	2200
18 MSMA	12 lf POST	19	1.4	46	25	38	1800
19 Untreated	—	18	1.5	47	24	40	2400
LSD (0.10)		NS	NS	7	NS	NS	500

[1] TN = number of mainstem nodes per plant, M = number of monopodium per plant, BR1 = boll retention position 1, BR2 = boll retention position 2, EBR = early boll retention defined as first and second positions on lowest five sympodia.

[2] Gly = glyphosate at 0.85 kg/ha, MSMA at 1.7 kg/ha. lf = cotton leaf stage above cotyledon, POST = postemergence over the-top, PDS = post-directed spray

CHAPTER IV
LONG TERM PURPLE NUTSEDGE (*CYPERUS ROTUNDUS*) CONTROL WITH GLYPHOSATE IN GLYPHOSATE TOLERANT SOYBEAN (*GLYCINE MAX*) AND COTTON (*GOSSYPIUM HIRSUTUM*)

Introduction

Purple nutsedge (*Cyperus rotundus* L.) has been identified as one of the world's worst weeds in the major agricultural areas of the world (Holm 1969), and has been widely documented for reducing crop yield (Keeley 1987, Elmore et al. 1983). It thrives under ideal conditions for crop growth including high soil moisture, high soil fertility and warm temperatures. Though purple nutsedge is relatively short in stature, it is very aggressive, enabling it to gain an early-season advantage in many crops. However once a dense canopy is formed by the crop, purple nutsedge is shaded thus reducing its competitive potential. Nonetheless, purple nutsedge can still be somewhat competitive under a crop canopy since 44 to 50% of the weed's dry weight is in underground rhizomes and tubers (Patterson 1982). Weed control would be facilitated if purple nutsedge tubers, the primary source of new plants, germinated simultaneously. However control is limited because many tubers remain dormant in the soil for an extended period of time, thus eluding typical control measures (Justice and Whitehead 1946).

Cyperus species are tolerant to many herbicides and are troublesome for soybean and cotton growers in the southeastern U.S. because they are difficult to control (Dowler 1998). Of the two predominant *Cyperus* species, purple nutsedge is more competitive

than yellow nutsedge (*Cyperus esculentus* L.) (Bendixen 1973) and there are fewer herbicides available for purple nutsedge control.

The uses of genetic engineering and advanced technology in cell culture techniques, in addition to traditional plant breeding, have produced crop plants which possess tolerance to herbicides, including glyphosate [*N* (phosphonylmethyl)glycine] (Barry et al. 1992, Padgette et al. 1995). Glyphosate is a broad spectrum, non-selective herbicide and effectively controls a wide spectrum of weeds, including purple nutsedge (Bryson et al. 1994, Horowitz 1972b, Horowitz 1992, Patterson 1982).

Even though glyphosate does not have any residual soil activity (Sprankel et al. 1975), it is particularly effective when foliar applied to purple nutsedge because it is translocated throughout the entire plant. Zandstra et al. (1974) reported purple nutsedge populations were reduced to a level where fast growing crops can compete, after one or two applications of glyphosate. These investigators also reported glyphosate was translocated to underground tubers, and affected the viability of the original and new developing tubers.

What is not fully understood are the survival capabilities of purple nutsedge in a cropping system that utilizes glyphosate as a principal means for purple nutsedge control. Furthermore, there are various selective herbicides available for purple nutsedge control, but little information is available for evaluating the influence these herbicides have on tuber populations. The objectives of these experiments were to compare glyphosate against conventional herbicide programs for purple nutsedge control in glyphosate-

tolerant soybean and cotton and to determine the influence these herbicide programs on purple nutsedge tuber populations.

Materials and Methods

Field experiments were conducted in 1997, 1998, and 1999 at the University of Florida's West Florida Research and Education Center located near Jay to evaluate long-term purple nutsedge control in both soybean and cotton. The soil was Red Bay fine sandy loam with 2.2% organic matter, 69% sand, 16% silt, and 15% clay (siliceous thermic Rhodic Paleudult). Both experiments were planted in an area naturally infested with purple nutsedge with an initial population of about 150 shoots per 0.25 m^2.

In the soybean experiment, 'Hartz 7555RR' was planted the fourth week of May. The entire test site received pendimethalin [*N* (1-ethylpropyl)-3,4-dimethyl-2 6-dinitrobenzenamine] at 1.1 kg/ha preplant incorporated with a power-driven roto-tiller for annual grass and small seeded broadleaf control. Herbicide treatments in the soybean experiment included an untreated check, glyphosate at 0.85 kg a.i./ha early postemergence (POST), glyphosate at 1.25 kg/ha early POST, glyphosate at 0.85 kg/ha early POST followed by glyphosate at 1.25 kg/ha POST, metribuzin at 0.57 kg/ha PRE followed by chlorimuron at 0.009 kg/ha plus a non-ionic surfactant at 0.25% v/v POST, and imazaquin at 0.14 kg/ha preemergence (PRE) followed by imazaquin at 0.14 kg/ha plus a non-ionic surfactant at 0.25% v/v POST. Herbicide treatments in the soybean experiment were randomized in a complete block design with four replications.

In the cotton experiment, 'Deltapine 5415 RR' was planted the first week of May in each year. Pendimethalin at 0.86 kg/ha plus fluometuron [*N,N*-dimethyl *N'*-[3

(trifluoromethyl)phenyl)]urea] at 1 7 kg/ha PRE was applied for grass and broadleaf weed control. Herbicide treatments for the cotton study included: an untreated check glyphosate at 1 14 kg a.i /ha POST over the-top at the 4-leaf cotton followed by glyphosate at 1 14 kg/ha POST-directed, glyphosate at 1 14 kg/ha POST over-the top at 4 leaf cotton followed by glyphosate at 0 57 kg/ha POST-directed norflurazon at 1 70 kg/ha PRE followed by cyanazine at 0 85 kg/ha plus MSMA [monosodium methanearsonate] at 2.27 kg/ha POST directed, and norflurazon at 1 70 kg/ha PRE followed by MSMA at 1 14 lg/ha POST over-the-top at 4-leaf followed by cyanazine at 0 85 kg/ha plus MSMA at 2 27 kg/ha POST-directed A split-plot treatment arrangement was utilized in the cotton experiment with early-season cultivation vs no cultivation as main plots and herbicide treatments as sub plots Cultivation was implemented in the row middle at approximately 2 and 6-leaf cotton with a 'sidder type' cultivator

Typical production practices such as fertilization, insect management for both crops, and defoliation for cotton were followed for Florida's panhandle. Experimental treatments were applied to the same plots for all 3 years of the study In the soybean experiment, plots were four rows (76 cm spacing) by 9 1 m and in the cotton study were eight rows (76 cm spacing) by 9 1 m

Data collected included visual purple nutsedge control relative to the untreated check and crop injury where 0 = no weed control or crop injury and 100 total weed control or crop death. Weed control was evaluated approximately 75 (mid season) and 105 days (late-season) after planting After the two center rows of each plot were harvested with commercial equipment, purple nutsedge tuber populations were quantified

by excavating a volume of soil 0 25 m^2 by 0 20 m deep from random locations within each plot Tubers were separated from the soil rinsed with water Tubers were then counted and planted in plastic trays (76 cm x 76 cm x 15 cm) using a soil medium with a ratio of 1-1 1 sand, peat, and vermiculite. If the sample size was >50 tubers, then 50 tubers were randomly selected for planting Collected tubers were placed in a greenhouse environment with 35C/25C day/night temperatures and were not limited in moisture and nutrients to test viability At weekly intervals for 6 weeks, sprouted tubers were recorded and removed from the plastic trays to ensure no growth inhibition of other non-sprouted tubers

Homogeneity of variance was evaluated prior to data analysis and data was subjected to ANOVA to test for treatment effects and possible interactions Means were separated using the General Linear Model procedure (SAS Institute 1987), with Fischer s Protected LSD test set at $P = 0.05$

Results and Discussion

Soybean Experiment

There was a treatment by year interaction ($P \leq 0.05$) for purple nutsedge control, tuber population and soybean injury and yield which prevented pooling There was not a treatment by year interaction ($P \geq 0.05$) for tuber viability and data was pooled across years

Glyphosate controlled purple nutsedge at least 90% regardless of rate, application timing, or year (Table 4 1) Glyphosate at 1 25 kg/ha performed better than either metribuzin PRE followed by chlorimuron POST (hereinafter referred to as chlorimuron)

or imazaquin PRE followed by imazaquin POST (hereinafter referred to as imazaquin) for early-season purple nutsedge control in 1997. There was no difference early-season between either chlorimuron and imazaquin, however, control generally improved from early season to mid-season with all treatments. Purple nutsedge is sensitive to shade, and once a crop forms a dense canopy the competitive potential of the weed is reduced (Ranade and Burns 1975, Patterson 1982). Mid season control was 98% in glyphosate treated plots in 1997, which was better than 89% with imazaquin or 81% with chlorimuron (Table 4.1).

There was no difference between glyphosate treatments and imazaquin in 1998 and each herbicide provided at least 90% purple nutsedge control (Table 4.1). Control with chlorimuron improved by mid-season and there were no differences in control between herbicide treatments. In 1999, glyphosate provided at least 96% control early season, better than the 90% control with either imazaquin or chlorimuron. In 1999 control again improved by mid-season, and all POST herbicide treatments provided comparable control.

In 1997, POST herbicides applied to soybean reduced purple nutsedge tubers overall by at least 56% (Table 4.1). Glyphosate was the most effective herbicide in 1997 and resulted in 70% reduction in tubers, compared to a 43 and 50% reduction with chlorimuron and imazaquin (Table 4.1). There were fewer tubers recovered from all treatments in 1998 compared to 1997, including the untreated check. Tuber populations were similar among herbicide treatments in 1998 and overall averaged 11 tubers per 0.25 m^2, compared to 64 per 0.25 m^2 in the untreated check. By 1999, purple nutsedge was

essentially eradicated in all herbicide treated plots as evidence by a lack of tubers recovered from soil (Table 4.1).

Herbicide treatments had a negative impact on tuber viability and glyphosate and imazaquin were most effective. Tuber viability was 57% in the untreated check, compared to 32% with chlorimuron, and <12% with glyphosate and imazaquin (data not shown).

In 1997 and 1998 chlorimuron and imazaquin treatments reduced early season soybean growth at least 13% compared to glyphosate treated plots (Table 4.2). There was also a 15 and 23% early-season reduction in soybean growth from nutsedge competition in 1997 and 1998 to the untreated check which was not observed in 1999. A possible explanation for a lack of reduction in soybean growth in the untreated check in 1999 may be due to the reduction in purple nutsedge population, thus reducing competition (Table 4.2). There was no observable reduction in soybean growth among herbicide treated plots by mid season in 1997 and 1998 (data not shown). In 1999, the untreated check resulted in 9% stunting mid-season, compared to 4 and 2% with chlorimuron and imazaquin (Table 4.2).

There was no difference in soybean yield between any glyphosate treatment in 1997, and each averaged 1600 kg/ha, better than either the untreated check or chlorimuron (Table 4.2). There was also no difference in yield between glyphosate and imazaquin in 1997. In 1998 there was no difference between yield of any treatment including the untreated check. In 1999 all herbicide treatments had comparable yields that overall averaged 2500 kg/ha, which was 20% higher than the untreated check.

Soybean yield in 1997 was much less than 1998 and 1999 presumably due to less mid-summer rainfall in 1997

Glyphosate was the most effective herbicide regardless of rate or application timing in reducing purple nutsedge population the first year of experimentation, which resulted in improved yield over the untreated check However, by mid season of the second year purple nutsedge populations were reduced among all treatments and either chlorimuron or imazaquin performed as well as glyphosate in controlling purple nutsedge. Furthermore, purple nutsedge populations were reduced enough by the second year that there was no yield difference between any herbicide treatment and the untreated check. By the third year, purple nutsedge tubers were nearly zero in all herbicide treated plots, and was reduced by 45% in the untreated check compared to 1997 The reduction of purple nutsedge tubers in the untreated check of the soybean experiment suggests that soybean is competitive against purple nutsedge and provides some level of control

Cotton Experiment

There was a treatment by year interaction ($P \leq 0.05$) and treatment by cultivation interaction ($P \leq 0.05$) in each year for all purple nutsedge and cotton data which prevented pooling.

Glyphosate was the most effective herbicide in 1997 and controlled purple nutsedge at least 90%, regardless of early season cultivation (Table 4.3) There was no difference early-season (40 days after planting) or mid season (70 days after planting) between glyphosate applied at 0.57 or 1.14 kg/ha POST directed following the POST

over the-top application at 1 14 kg/ha (Table 4 3) Norflurazon PRE followed by cyanazine plus MSMA POST-directed (hereinafter referred to only as MSMA POST directed) resulted in 54% early-season control but improved to 75% when cultivation was employed Cultivation also improved control from 71 to 89% early season with norflurazon PRE followed by MSMA POST followed by cyanazine plus MSMA post-directed (hereinafter referred to only as MSMA POST followed by POST-directed) (Table 4.3) Purple nutsedge control improved as the season progressed and cotton canopy increased

In 1997, in the absence of cultivation glyphosate treatments were more effective than the other treatments in reducing tuber populations Cultivation alone decreased tubers in the untreated check by 73%, 30% with MSMA POST-directed alone, 33% with MSMA POST followed by POST-directed alone, and 87% with MSMA POST followed by POST-directed with cultivation (Table 4 3) Glyphosate treatments reduced tuber viability by 85% compared to the untreated check in 1997 A single application of MSMA POST directed resulted in similar tuber viability as the untreated check However, tuber viability with the sequential MSMA treatment was not different from glyphosate treatments.

Cultivation alone resulted in 150% better yield than the untreated check in 1997 (Table 4 3) At least 12 and 6% early and mid season cotton growth reduction was observed when cultivation was not employed in the MSMA treated plots presumably due to purple nutsedge competition However even though cultivation with MSMA treated

plots improved purple nutsedge control it did not improve yield Glyphosate treated plots (+/- cultivation) yielded higher than any MSMA treatment in 1997 (Table 4 3)

Similar to 1997, glyphosate treatments were the most effective treatment for early-season purple nutsedge control in 1998 regardless of cultivation (Table 4 4) There was no difference between the sequential glyphosate treatment and sequential MSMA treatment for mid-season control in 1998 However more cotton growth reduction was observed in MSMA treated plots and cultivation alone in 1998 than 1997 presumably due to an early season drought in 1998 thus allowing a greater negative affect from uncontrolled purple nutsedge on cotton growth. Additionally yield was also affected from fall storms in 1998 which adversely affected the cotton crop throughout Florida's panhandle

Tuber populations were reduced among all treatments in 1998 compared to 1997 (Table 4 4 vs. 4 3) Cultivation alone reduced tubers an additional 71% compared to 1997 whereas glyphosate and MSMA POST followed by POST-directed reduced tubers an additional 64 and 78% respectively (Table 4 4)

Purple nutsedge control improved in 1999 among all treatments compared to 1997 and 1998 (Table 4 5 vs 4 3 and 4.4) Mid-season control in 1999 was 80% with cultivation alone, and at least 96% with a sequential application of glyphosate or MSMA regardless of cultivation A further reduction in tuber population was observed among all treatments except the untreated check in 1999 Purple nutsedge tuber population in the untreated check increased by 42% after 3 years of experimentation, compared to a 90% reduction using only cultivation for control (Table 4 5) MSMA POST-directed without

cultivation resulted in less tubers than the untreated check without cultivation, but had five times more tubers than glyphosate treated plots or MSMA POST followed by MSMA post-directed in 1999

In 1999, cultivation alone resulted in 78% purple nutsedge control, and at least 95% control was observed with either glyphosate +/- cultivation or MSMA with cultivation (Table 4 5) MSMA POST-directed without cultivation resulted in <60% control A single application of MSMA yielded higher than the untreated check, but not higher than cultivation alone. There was no difference in yield in 1999 between any glyphosate treatment or MSMA POST followed by POST-directed.

Soybean was more competitive against purple nutsedge than cotton as evidence by a 33% reduction in tuber population in the untreated check compared to a 42% increase in tubers in cotton over the 3 year study This may explain why yield from the untreated check in soybean in 1999 was only 20% less than herbicide treated plots compared to a 40% reduction in cotton

Glyphosate was the most effective herbicide program for initially controlling purple nutsedge and reducing tuber populations in both soybean and cotton In the second year of the soybean study, each herbicide program evaluated effectively controlled purple nutsedge In the cotton study, glyphosate was also the most effective herbicide program without the use of early-season cultivation MSMA treatments were equivalent to glyphosate provided cultivation was employed After 3 years, each herbicide program in both soybean and cotton proved to substantially reduce purple nutsedge populations resulting in effective control of purple nutsedge

Data presented in these studies support the conclusion that glyphosate-tolerant varieties provide growers with an option for effective purple nutsedge control in soybean and cotton. Furthermore, good purple nutsedge control was observed with glyphosate without the use of intensive management practices such as cultivation. Reduced tillage crop production is becoming more widely accepted by growers in the southeastern U.S. because of the several advantages with no tillage production systems such as reduced soil erosion, lower fuel requirements, greater flexibility in planting, reduced equipment requirements, and improved water retention (Phillips 1984). Given high populations of purple nutsedge, glyphosate should provide more effective control than traditional purple nutsedge control strategies. However, once purple nutsedge stands are reduced, other herbicide programs such as imazaquin in soybean and cultivation plus MSMA in cotton should prove comparable to glyphosate.

Table 4.1 Herbicide programs for long-term control of purple nutsedge in soybean 'Hartz 7550RR', Jay, FL.

			1997			1998			1999		
			Control			Control			Control		
Herbicide	Rate	Timing	40 DAP[1]	80 DAP	Tuber[4]	40 DAP	80 DAP	Tuber	40 DAP	80 DAP	Tuber
	kg/ha		%		0.25 m^2	%		0.25 m^2	%		0.25 m^2
Untreated			0	0	82	0	0	64	0	0	55
Glyphosate	0.86	EPOST	90	97	24	92	90	8	98	99	1
Glyphosate	1.25	EPOST	93	98	32	92	92	9	98	99	0
Glyphosate fb glyphosate	0.86	EPOST POST	90	98	25	95	99	12	96	99	0
Glyphosate fb glyphosate	0.86	EPOST POST	90	98	19	95	95	9	99	99	0
Metribuzin + chlorimuron	0.37	PRE POST	75	81	47	83	88	18	90	94	1
Imazaquin fb imazaquin	0.14	PRE POST	82	89	41	90	95	9	90	94	0
LSD (0.05)			10	7	17	7	NS	12	5	NS	39

[1] Entire study received pendimethalin pre plant incorporated at 1.14 kg/ha. Treatments applied to the same plot in each year

[2] Early postemergence (EPOST) = 2 weeks after soybean emergence (WAE), Postemergence (POST) = 6 WAE.

[3] Days after soybean planting (DAP)

[4] Soil samples were collected in the fall of each year to determine tuber population

Table 4 2 Soybean Hartz 7550RR stunting and yield in long term purple nutsedge control evaluation, Jay, FL[1]

			1997		1998		1999		
Herbicide	Rate	Timing[2]	Injury 40 DAP[3]	Yield	Injury 40 DAP	Yield	Injury 40 DAP	Yield	Injury 80 DAP[4]
	kg/ha		— % —	kg/ha	— % —	kg/ha	— % —	kg/ha	— % —
Untreated	—	—	15	600	23	2300	15	2000	9
Glyphosate	0 86	EPOST	0	1000	0	2500	0	2500	0
Glyphosate	1 25	EPOST	0	1000	0	2500	0	2500	0
Glyphosate	0 86	EPOST	0	1000	0	2600	0	2500	0
glyphosate	0 86	POST							
Glyphosate	0 86	EPOST	0	1000	0	2400	0	2500	0
glyphosate	1 25	POST							
Metribuzin	0 57	PRE	17	700	15	2600	12	2500	4
chlorimuron	0 009	POST							
Imazaquin	0 14	PRE	13	900	18	2600	10	2500	2
imazaquin	0 14	POST							
LSD@0 05			8	350		NS	5	300	6

[1] Entire study received pendimethalin pre-plant incorporated at 1 14 kg/ha. Treatments applied to the same plot in each year

[2] Early postemergence (EPOST) = 2 weeks after soybean emergence (WAE), Postemergence (POST) = 6 WAE

[3] Days after soybean planting (DAP)

[4] Data pooled across year

Table 4.3 Herbicide programs for long term purple nutsedge control in cotton. DP 5415 RR', Jay, FL 1997 [1]

Herbicide	Rate	Timing	Cult.[2]	Purple nutsedge				Cotton		
				Control		Tuber		Injury		Seed yield
				40 DAP	70 DAP	No	Germ	40 DAP	70 DAP	
	kg/ha			%		0.25 m^{-2}	%	%		kg/ha
Untreated	—	—		0	0	304	75	34	15	1000
Untreated	—	—	+	58	65	83	66	19	11	2500
Glyphosate	1.14	POST	–	93	93	58	9	0	0	3500
glyphosate	1.14	PDS								
Glyphosate	1.14	POST	+	91	90	31	17	0	0	3400
glyphosate	1.14	PDS								
Glyphosate	1.14	POST	–	93	93	38	11	0	0	3400
glyphosate	0.57	PDS								
Glyphosate	1.14	POST	+	91	93	40	8	0	0	3400
glyphosate	0.57	PDS								
Norflurazon	1.70	PRE		54	61	213	73	13	15	2900
cyanazine + MSMA	0.86 + 2.28	PDS								
Norflurazon	1.70	PRE	+	75	79	103	36	0	0	3000
cyanazine + MSMA	0.86 + 2.28	PDS								
Norflurazon	1.70	PRE		71	80	203	38	12	6	2900
MSMA	1.14	POST								
cyanazine + MSMA	0.86 + 2.28	PDS								
Norflurazon	1.70	PRE	+	89	93	41	48	0	0	3000
MSMA	1.14	POST								
cyanazine + MSMA	0.86 + 2.28	PDS								
LSD 0.05				8	10	36	33	3	3	350

[1] Entire study received pendimethalin pre-plant incorporated at 0.86 kg/ha and fluometuron pre-emergence (PRE) at 1.7 kg/ha. Abbreviations: DAP = days after planting; POST = postemergence; PDS = post-directed spray. Soil samples collected in the fall subsequent to harvest to determine tuber population.

[2] With or without early-season cultivation.

Table 4 4 Herbicide programs for long-term purple nutsedge control in cotton 'DP 5415 RR' Jay, FL 1998 [1]

Herbicide	Rate	Timing	Cult [2]	Purple nutsedge				Cotton		
				Control		Tuber		Injury		Seed
				40 DAP	70 DAP	No	Germ	40 DAP	70 DAP	yield
	kg/ha			%		0 25 m^2	%	%		kg/ha
Untreated	—	—	-	0	0	324	83	40	50	350
Untreated	—		+	60	71	24	50	6	14	1200
Glyphosate	1 14	POST	-	88	94	14	30	0	0	1600
glyphosate	1 14	PDS								
Glyphosate	1 14	POST	+	85	99	3	8	0	0	1700
glyphosate	1 14	PDS								
Glyphosate	1 14	POST		85	85	20	5	0	0	1600
glyphosate	0 57	PDS								
Glyphosate	1 14	POST	+	88	99	5	7	0	0	1700
glyphosate	0 57	PDS								
Norflurazon	1 70	PRE		35	38	143	62	35	35	1000
cyanazine + MSMA	0 86 + 2 28	PDS								
Norflurazon	1 70	PRE	+	63	95	8	49	0	0	1600
cyanazine + MSMA	0 86 + 2 28	PDS								
Norflurazon	1 70	PRE		63	89	12	45	23	25	1300
MSMA	1 14	POST								
cyanazine + MSMA	0 86 + 2 28	PDS								
Norflurazon	1 70	PRE	+	73	99	9	21	13	3	1600
MSMA	1 14	POST								
cyanazine + MSMA	0 86 + 2 28	PDS								
LSD (0 05)				8	9	20	26	10	13	250

Entire study received pendimethalin pre-plant incorporated at 0 86 kg/ha and fluometuron pre-emergence (PRE) at 1 7 kg/ha. Abbreviations DAP = days after planting, POST = postemergence, PDS = post directed spray. Soil samples collected in the fall subsequent to harvest to determine tuber population.

[2] With or without early-season cultivation.

Table 4.5 Herbicide programs for long-term purple nutsedge control in cotton, DP 5415 RR[1], Jay, FL 1999 [2]

Herbicide	Rate	Timing	Cult.[3]	Purple nutsedge				Cotton		
				Control		Tuber		Injury		Seed yield
				40 DAP	70 DAP	No.	Germ	40 DAP	70 DAP	
	kg/ha			— % —		0.25 m^2	— % —	— % —		kg/ha
Untreated	—	—	-	0	0	433	77	50	41	2170
Untreated	—	—	+	78	80	33	68	8	13	2980
Glyphosate	1.14	POST		88	99	7	24	0	0	3540
glyphosate	1.14	PDS								
Glyphosate	1.14	POST	+	98	99	4	25	0	0	3160
glyphosate	1.14	PDS								
Glyphosate	1.14	POST		90	97	11	29	0	0	3490
glyphosate	0.57	PDS								
Glyphosate	1.14	POST	+	97	99	4	6	0	0	3330
glyphosate	0.57	PDS								
Norflurazon	1.70	PRE		53	58	71	70	21	20	2900
cyanazine + MSMA	0.86 + 2.28	PDS								
Norflurazon	1.70	PRE	+	95	99	3	0	0	0	3090
cyanazine + MSMA	0.86 + 2.28	PDS								
Norflurazon	1.70	PRE		83	96	9	36	18	16	3490
MSMA	1.14	POST								
cyanazine + MSMA	0.86 + 2.28	PDS								
Norflurazon	1.70	PRE	+	95	99	3	15	0	0	3500
MSMA	1.14	POST								
cyanazine + MSMA	0.86 + 2.28	PDS								
LSD 0.05	—	—		7		27	33	11	9	450

Entire study received pendimethalin pre-plant incorporated at 0.86 kg/ha and fluometuron pre-emergence (PRE) at 1.7 kg/ha. Abbreviations: DAP = days after planting; POST = postemergence; PDS = post-directed spray. Soil samples collected in the fall subsequent to harvest to determine tuber population.

[1] With or without early-season cultivation.

CHAPTER V
THE INFLUENCE OF GLYPHOSATE AND CULTIVATION ON PURPLE NUTSEDGE (*CYPERUS ROTUNDUS*) TUBER POPULATIONS

Introduction

Purple nutsedge (*Cyperus rotundus* L.) is an aggressive weed found in most parts of the world (Holm 1969, Bendixen and Nandihalli 1987) and is particularly a problem in agronomic crops of the southeastern U.S. (Dowler 1998). Purple nutsedge is also known as "nutgrass" due to its extensive underground system of bulbs, tubers, and rhizomes (Hauser 1962a). The plant generally produces numerous seeds, however, reproduction is primarily by bulbs and tubers since only a small portion of the seed are viable (Justice and Whitehead 1946). Additionally, each tuber may possess 10 or more buds (Horowitz 1972b) that are each capable of producing an aerial shoot or additional rhizomes, which in turn may produce chains of tubers and rhizomes (Neeser et al. 1997). The infestation potential of purple nutsedge is significant considering tubers may be formed within 10 to 20 days after seedling emergence (Ranade and Burns 1925).

Many investigators have cited the vast production of tubers by purple nutsedge. Hauser (1962b) reported that 6 weeks after shoot emergence, the subterranean network of bulbs, tubers, and rhizomes possessed a mass greater than that of the foliage. Typically, 44 to 70% of the weed's dry weight is comprised of underground rhizomes and tubers (Williams 1982). Smith and Frick (1937) reported a single tuber produced 146 bulbs and tubers within 14 months. Rao (1968) observed that 1 parental tuber produced 99 basal

bulbs and tubers in 90 days Hauser (1962b) found that tubers planted at 30 5cm intervals could produce over 1 2 million plants/ha and 1 8 million bulbs and tubers/ha in the first year of infestation By the end of the second season it was calculated that 2 million plants/ha had been produced with over 5 million bulbs and tubers/ha

Tuber germination is highest, and shoots emerge fastest, for those closest to the soil surface Investigators have reported that most tubers reside in the top 20 cm of the soil, and are rarely found beneath 30 cm (Smith and Frick 1937 Stoller and Sweat 1987). Additionally, less than 1% of viable tubers in a sandy soil are found beneath the plow depth However, when purple nutsedge is controlled for 2 consecutive years with no new tuber production, Smith and Frick (1937) reported tuber germination from a depth of more than 30 cm Siriwardana and Nishimoto (1987) determined that tuber fresh weight and dry weight, in addition to the percentage of dry matter increased with soil depth Storing more food reserves in tubers produced deeper in the soil is a survival mechanism of purple nutsedge that increases the likelihood of these of these tubers producing new plants

Effective control of purple nutsedge has been achieved with glyphosate [*N*-(phosphonylmethyl)glycine] (Zandstra et al 1974 Bryson et al 1994) Glyphosate inhibits the enzyme 5-enolpyruvylshikimate-3 phosphate synthase (EPSPS), preventing the plant from synthesizing aromatic amino acids essential for plant growth (Franz 1996) Many investigators have reported that glyphosate is effective for purple nutsedge control since it is rapidly absorbed and translocated to underground structures reducing tuber viability (Sprankel et al 1975, Zandstra and Nishimoto 1977, Doll and Piedrahita 1982)

Translocation of the herbicide to the underground structures is important since the vascular system of below-ground structures may stay intact long after aerial shoots have been removed (Hauser 1962b)

Frequent tillage has also resulted in purple nutsedge control. Eradication of purple nutsedge has been achieved with thorough disking timed at 2 to 3 week intervals for 2 growing seasons (Westmoreland et al 1955) Tillage may kill tubers provided the roots that supply moisture are cut (Andrews 1940)

Tubers in their natural state contain approximately 85% water and drying them to 15% water will kill them, while simply a reduction in moisture will result in reduced viability (Smith and Frick 1937) Rao and Nagarajan (1963) observed germination reduction when tubers were sun-dried for 12 hours and a complete lack of germination when the drying period was extended for 48 hours. The water content of tubers is relevant in tillage operations because tillage will bring tubers to the surface reducing their numbers by desiccation

Cultivation has also been reported to increase the level of purple nutsedge infestation Rao (1968) reported cultivated areas had twice the population of uncultivated areas This phenomenon can be attributed to a break in the apical dominance of the tuber chain during cultivation inducing the sprouting of dormant or quiescent tubers

This study further investigates the biology of purple nutsedge as it relates to tuber populations There have been studies which describe the characteristics of a viable tuber and a tuber population in a given soil profile (Rao 1986, Rao and Nagarajan 1963 Smith

and Meyton 1937) This study was implemented to evaluate tuber viability and longevity as affected by glyphosate application and cultivation

Materials and Methods

A field experiment was conducted from 1995 to 1999 at the University of Florida West Florida Research and Education Center in Jay, FL in an area naturally infested with purple nutsedge May through August rainfall typically averaged 15 cm per month (Table 5 1) with minimum and maximum air temperatures of 21 and 33 C respectively (Table 5.2) The soil was Red Bay fine sandy loam with 2.2% organic matter 69% sand, 16% silt, and 15% clay (siliceous thermic Rhodic Paleduit)

During the first week of May in 1995 and each successive spring through 1999, the entire test site was cultivated with a disk harrow to remove winter annual weeds and prepare a seed bed for purple nutsedge growth Following spring cultivation the entire test area received pendimethalin [*N*-(1-ethylpropyl) 3,4-dimethyl-2,6-dinitrobenzenamine] at 1 12 kg/ha plus fluometuron [*N,N*-dimethyl-*N*'-[3-(trifluoromethyl)phenyl)]urea] at 1.68 kg/ha PRE for annual grass and broadleaf weed control Experimental treatments consisted of an untreated check (natural reproduction) glyphosate at 0 85 kg/ha, and glyphosate at 0 85 kg/ha followed by cultivation with a rototiller approximately 3 weeks later Treatments were applied to the same plots each year of the study

Glyphosate was applied throughout the warm-season of each year from May through August whenever purple nutsedge had emerged in the experimental plots In 1995 through 1998 applications were applied in the beginning of June with a sequential

treatments following in mid-July In 1999, a single application was made 10 June without a sequential treatment due to a lack of purple nutsedge population Cultivation was targeted approximately 3 weeks after glyphosate application unless purple nutsedge plants had emerged If nutsedge had emerged, glyphosate was once again applied without the cultivation treatment and cultivation proceeded 3 weeks later The cultivation treatment was implemented with a rotohiller which thoroughly tilled the upper 15 cm of soil.

Treatments were randomized in a complete block design with 4 replicates and plots were 6 1 by 9 1 m Tuber analysis was conducted during the fall of each season by randomly extracting 1 0 m^2 by 0 20 m deep of soil from each plot Tubers were separated from soil and then counted and rinsed In 1997, 1998 and 1999, tubers were tested for viability by planting in plastic trays (76 cm x 76 cm x 15 cm) using a soil medium with a ratio of 1 1 1 sand, peat, and vermiculite If the sample size was >50 tubers, then 50 tubers were randomly selected for planting Collected tubers were placed in a greenhouse environment with 35C/25C day/night temperatures and were not limited in moisture and nutrients At weekly intervals for 6 weeks, sprouted tubers were recorded and removed from the plastic trays to ensure no growth inhibition of other non-sprouted tubers Tuber number and germination data was subjected to ANOVA using the General Linear Model procedure (SAS Institute 1987)

Results and Discussion

There was a treatment by year interaction for tuber and germination data ($P<0.001$ level) therefore, data was separated and presented by year In the untreated check where

purple nutsedge growth was uninhibited tuber production increased linearly (Table 5 3) Tuber production increased 100% from 1995 to 1996 similar to the results of Webster and Coble (1997) who reported a 141% increase in tuber density at the end of first year in the untreated check Tuber production continued to increase through 1999 where a 36-fold increase was observed compared to 1995 (Table 5.3).

There was no significant difference ($P>0.05$) in tuber production during 1995 between the untreated check and glyphosate followed by cultivation (Table 5 3) Cultivation significantly increased tubers ($P<0.01$) in 1995 by 110% compared with glyphosate alone Although cultivation in combination with herbicides has been shown to decrease tuber populations in cropping systems (Webster and Coble 1997), other investigators have cited tuber density increases (Graham 1995, Rao 1968) Including cultivation in the glyphosate treatment increased tuber production ($P<0.001$) by ten-fold in 1997 compared to glyphosate alone and by 19 fold in 1998 However, a ten fold reduction from 1998 to 1999 was observed with glyphosate followed by cultivation

Glyphosate applied alone resulted in a reduction of tuber populations from the onset of experimentation (Table 5 3) In 1998 after 3 years, glyphosate alone had resulted in an observable depletion in the purple nutsedge population In 1999 purple nutsedge was essentially eradicated where glyphosate alone was applied (Table 5 3)

Purple nutsedge tuber viability was at least 77% as noted by shoot emergence under greenhouse conditions, where glyphosate was not applied (Table 5 3) Glyphosate application reduced tuber viability by at least 85% This data is similar to Zandstra and Nishimoto (1977) who reported that 12-week old purple nutsedge plants treated with

glyphosate resulted in only 5% sprouting of tubers Cultivation had no affect on tuber germination where glyphosate was applied (Table 5 3)

Purple nutsedge has been noted as one of the world s worst weeds because it is difficult to control Conventional suppression of purple nutsedge generally includes tillage and/or herbicides but complete eradication of viable tubers is difficult (Doll and Piedrahita 1982) Control would be facilitated if tuber dormancy were only a short period of time. However control is limited because many tubers remain dormant in the soil for an extended period of time (Miles et al. 1996), thus eluding typical control measures

Our results demonstrate that glyphosate is an effective herbicide in eradicating purple nutsedge Other investigators have cited reductions in purple nutsedge populations due to repeated applications of glyphosate (Zandstra et al 1974) or other herbicides and/or cultivation (Webster and Coble 1997). However in each of these studies experimental treatments were not continued long enough to deplete all viable tubers in the soil profile and reinfestation would be likely if control measures were not continued (Horowitz 1972)

Understanding tuber longevity of nutsedge species is critical in understanding how tuber populations are influenced by various methods of control Stoller and Wax (1973) reported that yellow nutsedge (*Cyperus esculentus* L) half life in a laboratory-determined analysis was 4 4 and 5 7 months for tubers buried at depths of 10 2 and 20.3 cm, respectively Neeser et al (1997) reported the tuber half-life for 50% mortality of purple nutsedge was predicted at 16 months, much longer than the tuber half life reported of yellow nutsedge by Stoller and Wax (1973) In this study, after the first year of

glyphosate application without cultivation, tuber population was reduced by 50% (Table 5.3). However, even though the half-life of purple nutsedge may be only 16 months, it is important to consider that 4 years of herbicide application with glyphosate was required to deplete the purple nutsedge population to a manageable level, and 5 years was required for eradication.

Table 5 1 Monthly rainfall at the University of Florida West Florida Research and Education Center Jay FL

	1995	1996	1997	1998	1999
			cm		
January	15	14	12	28	16
February	7	12	17	21	4
March	17	27	10	23	14
April	16	23	16	10	6
May	21	2	10	8	15
June	11	11	23	3	22
July	21	18	17	16	16
August	25	24	17	11	9
September	11	13	5	55	3
October	43	3	12	1	11
November	23	7	27	15	8
December	12	13	11	10	9
Total	221	166	176	199	133

Table 5 2 Monthly average minimum and maximum air temperature at the University of Florida West Florida Research and Education Center Jay FL

	1995		1996		1997		1998		1999	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
					Celcius					
January	5	16	2	16	5	18	6	17	6	18
February	5	18	5	19	7	18	6	18	7	19
March	11	22	6	19	13	25	8	20	7	21
April	13	25	10	23	11	24	12	24	15	28
May	19	31	17	31	15	28	17	32	16	30
June	20	33	20	32	20	30	22	35	21	32
July	22	34	22	33	23	33	23	35	22	33
August	22	34	21	33	21	33	22	34	23	35
September	19	32	19	31	19	34	23	31	17	32
October	13	27	12	26	13	27	15	29	13	27
November	6	20	8	22	6	19	14	27	7	23
December	5	15	5	19	5	15	11	19	4	16

Table 5 3 Orthogonal contrasts of glyphosate herbicide and cultivation on purple nutsedge tubers and germination, Jay, FL [1]

Contrast	1995	1996	1997		1998		1999	
	tubers[2]	tubers	tubers	germ	tubers	germ	tubers	germ
	-- m^2 --	-- m^2 --	-- m^2 --	-- % --	-- m^2 --	-- % --	-- m^2 --	-- % --
untreated vs	133 * [3]	267 **	2388 **	77 **	2258 ***	99 **	4478 ***	87 ***
glyphosate as needed	69	41	38	6	14	11	1	0 3
untreated vs	133 ns	267 **	2388 **	77 **	2258 ***	99 ***	4478 ***	87 **
glyphosate as needed (fb) cultivation	145	197	384	13	268	19	22	1 5
glyphosate as needed vs	69 **	41 *	38 ***	6 ns	14 ***	11 ns	1 **	0 3 ns
glyphosate as needed (fb) cultivation	145	197	384	13	268	19	22	1 5

[1] Treatments applied to same plot area in each year of experimentation and included an untreated control, glyphosate at 1 14 kg/ha as needed when sprouts emerged during each growing season, and glyphosate at 1 14 kg/ha as needed followed by (fb) cultivation with a rototiller

[2] Tubers were collected in the fall of each year by sampling 1 meter^2 of soil from each plot

[3] *, **, and *** are significant at p = 0 05, 0 01, and 0 001, respectively

CHAPTER VI
THE USE OF PLANT GROWTH REGULATORS WITH HERBICIDES FOR PURPLE NUTSEDGE (*CYPERUS ROTUNDUS*) CONTROL

Introduction

Purple nutsedge (*Cyperus rotundus* L.) has been designated as one of the world's worst weeds because it is difficult to control (Holm 1969). Conventional weed control generally includes tillage, and/or herbicides. Hamnerton (1974) evaluated the effect of 2,4-D [(2,4-dichlorophenoxy)acetic acid] and paraquat [1,1'-dimethyl-4,4' bipyridinium ion] on the growth and development of purple nutsedge. Both herbicides reduced foliage growth, but had little effect on tuber production. More effective control of purple nutsedge has been achieved with glyphosate [*N* (phosphonylmethyl)glycine] (Zandstra et al. 1974, Bryson et al. 1994) and imidazolinone herbicides (Vencill et al. 1995, Molin et al. 1999). Control is limited because many tubers remain dormant in the soil for an extended period of time (Smith and Frick 1937, Sriwardan and Nishimoto 1987, Neeser et al. 1997), thus eluding typical control measures.

Purple nutsedge is a perennial weed with an extensive underground system of rhizomes, tubers (swollen ends of rhizomes specialized for storing food reserves that contains 10 to 14 buds), and bulbs (vertical underground stems modified for food storage with a single growing point) (Hauser 1962). Reproduction is primarily by bulbs and tubers since only a fraction of the seeds produced are viable (Justice and Whitehead

1974). Typically, 44 to 70% of the weed's dry weight is comprised of underground rhizomes and tubers (Wilhams 1982). Each tuber may possess 10 or more buds (Horowitz 1972b) each capable of producing an aerial shoot or additional rhizomes. Underground tuber chains, as well as buds on individual tubers, exhibit apical dominance for sprouting new shoots (Smith and Frick 1937). The apical bud of the tuber inhibits the release of the buds below, and the tuber at the apex of a rhizome tuber chain prevents sprouting of other tubers on the chain (Hauser 1962a).

The use of plant growth regulators (PGRs) to alter the growth habit of plants is widely documented (Woolley and Wareing 1972, Yogev et al. 1996). Gibberellins, or gibberellic acid (GA), promote plant growth, seed germination, and flowering (Kane et al. 1995, Rehm and El-Masry 1976). Gibberellic acid may also stimulate negative geotropic responses (Bendixen 1970). PGRs capable of inducing cytokinesis, or cell division, are called cytokinins. Both cytokinins and GA may also overcome apical dominance in some plants and prevent the inhibition of lateral bud development (Teo et al. 1973). Abscisic acid (ABA) is another plant growth regulator that can cause bud dormancy (Jangaard et al. 1971) as well as the senescence and abscission of leaves (Addicott and Lyon 1969).

Purple nutsedge tuber dormancy has been attributed to more than one inhibitory substance (Jangaard et al. 1971, Hemberg 1958, Teo et al. 1974). Hemberg (1958) and others have collectively referred to these substances as the inhibitor β complex (Ueki 1969). Using chromatography and bioassay analysis of the inhibitor β complex, Teo et al. (1974) found that phenolic compounds in the presence of ABA were responsible for the inhibition of coleoptile elongation and bud sprouting. Ueki (1969) has suggested that

such inhibitors are water soluble since washing of tubers increases the number of sprouts per tuber

Teo et al (1973) reported that dormant tubers are deficient in cytokinins and that this hormone is a required agent for germination instead of a trigger mechanism They found that when tubers were placed in a cytokinin containing media, more sprouts were produced than when tubers were simply soaked in the hormone solution for a short period These findings were supported by Bendixen (1975) who found that cytokinins break tuber dormancy and apical dominance, resulting in basal bud formation The reports of the various effects of growth hormones on purple nutsedge tuber dormancy suggests that there is a relationship or balance between growth promoters and inhibitors

Investigators have continued to evaluate the use of PGRs with nutsedge in an attempt to increase its control with herbicides Teo and Nishimoto (1973) reported that two applications of benzyladenine (BA) a cytokinin at 50 ppm resulted in 70 to 90% of the buds present on individual tubers sprouting thus forming above-ground shoots. After sprouted buds were removed, additional applications of cytokinins or proper growing conditions for a duration of 39 days did not produce any additional sprouting However in an earlier study by Teo (1971 unpublished) plants routinely treated with foliar applied BA resulted in an altered growth habit of increased rhizome and basal bulb formation.

Chetram and Bendixen (1974) investigated the effects of cytokinins and GA on rhizomes produced by basal bulbs of purple nutsedge. In this study control plants, and those treated with GA, kinetin and BA resulted in the production of only under-ground bulbs The number of above-ground bulbs was significantly higher with BA + GA than

with kinetin + GA. The bulbs that developed above-ground did not produce roots and therefore, did not have the capacity to produce any additional tubers. These results suggest a synergistic effect of cytokinin and GA in stimulating the growth of basal bulbs and inducing a negative geotropic response of purple nutsedge rhizomes.

Yogev et al. (1996) investigated control of purple nutsedge using applications of PGRs with and without herbicides. Plants sprayed with four applications of a mixture of BA ($6x10^{-4}$ M) + GA_3 ($4x10^{-3}$ M) produced results similar to those reported by Chetram and Bendixen (1974). In Yogev's experiments, plants increased above-ground growth with the inhibition of tuber production. These investigators also evaluated two applications of BA + GA_3 followed by the application of selected herbicides. The combination of PGRs followed by herbicide was better for reducing tuber populations than herbicides used alone.

Yogev et al. (1996) reported that the combination of hormones with either MSMA [monosodium methanearsonate] or glyphosate reduced tuber numbers to < 2 per plant compared to 20 tubers per plant in the control and 5.5 tubers per plant in the PGR only treatment when evaluated 140 days after the herbicide treatments were applied.

Control of nutsedge species with herbicides is limited due to apical dominance within tuber chains and tuber bud dormancy (Zandstra and Nishimoto 1977; Hauser 1962b; Williams 1982). The most effective control is achieved with the use of herbicides that are translocated from foliage to the tuber. However, multiple herbicide applications are generally needed due to the presence of single dormant tubers in the soil (Zandstra et

al 1974), or ineffective translocation throughout the tuber chain (Zandstra and Nishimoto 1977)

Gibberellins, cytokinins and ABA are PGRs that have been reported to affect the growth of purple nutsedge (Bendixen 1975 Teo et al 1974, Teo and Nishimoto 1973) The synergistic effect of BA + GA on altering purple nutsedge growth has also been documented (Chetram and Bendixen 1974) These experiments seek to further explore the use of PGRs for purple nutsedge management. The objective of this research was to determine whether pre-conditioning purple nutsedge with BA+ GA would facilitate control with herbicides.

Materials and Methods

Preliminary Glasshouse Experiments

Studies were conducted at the University Florida Turfgrass Environon in Gainesville during 1997 1998 and 1999 Purple nutsedge tubers used in these experiments were collected from infested fields at University of Florida's West Florida Research and Education Center located in Jay FL Experiments were conducted in a glasshouse environment with 35C/25C day/night temperatures and were not limited in moisture or nutrients. In each of these experiments artificial lights were used to ensure at least a 12 hour photoperiod. Promalin®,[1], a proprietary formulation of BA + GA, was used as the PGR in both the glasshouse and field experiments Single pre-sprouted purple nutsedge tubers were planted at a depth of 2 cm in pots (16 cm wide and 11 5 cm in

[1] Promalin®: a proprietary formulation of 1 8% N⁶ benzyladenine (BA) plus 1 8% gibberellin $_{4\ 7}$ (GA) Abbott Laboratories, North Chicago, IL.

height) with a potting medium of 1 1 sand and peat moss. Water and nutrients were supplied to plants as needed

The first glasshouse experiment investigated the influence of PGR rates on purple nutsedge growth and tuber development. Rates of BA + GA included 0, 125, 250, 375, 500, 625, 750, 875 and 1000 ppm. Because Promalin® contains equal concentrations of BA and GA, the reported ppm is representative of each growth hormone in solution. Two foliar treatments were applied with a syringe at 1 ml per plant 2 and again 3 weeks after shoot emergence. The PGR solution was divided between two fully expanded purple nutsedge leaves and included a non-ionic surfactant at 0.25% v/v.

Shoot number and length were recorded four times at biweekly intervals beginning 2 weeks after the second PGR application. Eight weeks after initial treatment (WAIT) application, shoots were harvested and dry weights recorded. Potting medium was rinsed from the tubers and tubers were counted. The rate study, done prior to the stage of development study, was conducted once and consisted of four replications.

The second preliminary glasshouse study investigated the influence of BA + GA application timing on purple nutsedge. Benzyladenine + GA at 0, 25, 50, 100, 200, and 300 ppm were applied to purple nutsedge at 3 growth stages: 1 week after emergence (WAE)(12 cm with 2 shoots/pot), 3 WAE (29 cm with 4 shoots/pot), and 6 WAE (53 cm with 12 shoots/pot). A second application was made one week after each initial treatment. Treatments were applied to entire plants using a laboratory spray booth with 8002E nozzle tips calibrated to deliver a 190 L/ha solution at 220 kPa. Four WAIT shoot height and shoot number were recorded. Afterwards, plants were removed from the soil

medium and separated into above-ground and below-ground biomass. Both were dried at 70 C for 72 hours and then weighed. The experiment was conducted twice, each with four replications.

Field Experiments. Experiments were conducted in 1998 and 1999 at the University of Florida West Florida Research and Education Center in Jay, FL in an area naturally infested with purple nutsedge. The soil type was a Red Bay fine sandy loam with 2.2% organic matter, 69% sand, 16% silt, and 15% clay (siliceous, thermic Rhodic Paleudult). Plots were 3 m by 6 m and each experiment was conducted utilizing a randomized complete block with 4 replications. The entire experimental area was tilled with a power-driven rototiller prior to study initiation. Treatments (both herbicide and PGR) were applied with a CO_2-pressurized backpack hand-held boom-sprayer calibrated to deliver 190 L/ha at 220 kPa with 8002VS nozzle tips following purple nutsedge emergence.

Three weeks following the final herbicide application, visual control was evaluated based on a scale from 0 to 100, where 0 = no weed control and 100 = total weed control. Immediately following weed control evaluations the entire test site was cultivated with a rototiller. Three weeks after cultivation purple nutsedge re-infestation was determined by counting shoots/0.25 m^2. The average of two sub-samples were used for data analysis from each plot.

A preliminary field study was initiated the first week of June 1998 to determine the impact of pre-conditioning purple nutsedge with growth promoters (BA + GA) on herbicide effectiveness in reducing purple nutsedge populations. Herbicides chosen in

this experiment were paraquat at 0 6 kg/ha, MSMA at 2.2 kg/ha, and glyphosate at 1 1 kg a i/ha, where paraquat is translocated the least in plants and glyphosate is translocated the most Treatments included herbicide application 3WAE, herbicide 3WAE followed by a second application 6WAE, BA + GA at 100 ppm applied 3 and 4 WAE followed by herbicide 6WAE and BA + GA at 300 ppm applied 3 and 4 WAE followed by herbicide 6WAE

The second field experiment was initiated the first week of May and June 1999 The experiment was split plot in design (PPI vs no PPI) with BA + GA at 380 L/ha applied PPI as the main plot. Split-plots were herbicide application 3WAE herbicide 6WAE herbicide 3WAE followed by a second application 6WAE, and BA + GA at 100 ppm 3 and 4WAE followed by herbicide 6WAE Glyphosate at 1 1 kg/ha, imazapic [(+-)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5 oxo-1*H*-imidazol-2-yl]-5 methyl-3 pyridinecarboxylic acid] at 0 07 kg/ha, and halosulfuron [methyl 5-[[(4 6-dimethoxy 2 pyrimidinyl)amino]carbonylaminosulfonyl]-3 chloro-1-methyl-1 *H*-pyrazole-4-carboxylate] at 0 07 kg/ha were the herbicides used in the 1999 field study Glyphosate halosulfuron and imazapic were chosen because of their effectiveness for purple nutsedge control (Vitelli et al 1995, Ahrens 1994)

All experiments consisted of four replications Data in each experiment was evaluated for homogeneity prior to analysis and subjected to ANOVA using the General Linear Model procedure (SAS Institute 1987) to test for main effects and interactions

Results and Discussion

Preliminary Glasshouse Studies

In the preliminary PGR rate study, BA + GA significantly ($P<0.05$) increased purple nutsedge shoot height at all rates (75 to 1000 ppm) (Table 6.1). Four weeks after treatment (WAT) BA + GA at 75 and 125 ppm increased shoot height by 67 and 100%, whereas BA + GA rates >125 ppm generally did not increase height until 8 WAT (Table 6.1). There was no shoot number response for any treatment at 2 weeks. However, by 4 weeks BA + GA at 125 ppm increased shoot number by 50% over the untreated control.

The preliminary PGR rate experiment was terminated at 8 weeks and above-ground biomass was collected and under ground tubers were counted. Even though BA + GA elicited an observable change in growth by increasing shoot height and number, there was no treatment effect for above-ground shoot biomass (Table 6.1). PGR treatments were effective in reducing tuberization by 95, 100, 79, 63, 63, and 63% when applied at 75, 250, 375, 500, 625, and 750 ppm (Table 6.1). Based on increases in shoot height and tuber reduction from PGR rates, there was no advantage in using BA + GA at a rate higher than 250 ppm.

There was a treatment by year interaction ($P<0.05$) for the timing of application study which prevented pooling. In 1998, BA + GA applied as a sequential treatment to 1 week old nutsedge had no effect on growth and development (Table 6.2). When applied to 3 week old nutsedge, none of the treatments had an effect on shoot height, but BA + GA at 100 ppm increased shoot number by 15%. There was also a reduction in tuberization with BA + GA at a rate of ≥50 ppm with no increases in tuber reduction at a

rate>300 ppm. There was no observable effect on purple nutsedge growth when applied to 6 week old nutsedge (Table 6.2). Even though the 6 week timing did not affect shoot height or sprout number a 13-fold reduction in tuber production was observed at 100 ppm compared to the untreated check.

Benzyladenine + GA promoted purple nutsedge growth at all timings in 1999. Benzyladenine + GA applied 1 WAE increased shoot height by 25% at 25 ppm and 71% at 200 ppm over the untreated check (Table 6.3). When applications were made 3 WAE, BA + GA generally did not increase shoot height but tuberization was reduced by at least 67% at 25 to 100 ppm. Similar observations in growth were observed when BA + GA were applied 6 WAE (Table 6.3).

Benzyladenine + GA had a positive effect on purple nutsedge growth. For each of the applications evaluated, the 6 week treatment reduced tuberization the most (Tables 6.2 and 6.3). However, such a delay in application is impractical since purple nutsedge is known to produce tubers within 10 to 20 days after seedling emergence (Ramalo and Burns 1925) and would likely increase weed infestation if control measures were delayed six weeks in a natural population.

Application 1 WAE had no effect on nutsedge growth in 1998 (Table 6.2), and only a height increase was observed in 1999 (Table 6.3). In 1998, applications to 3 week old nutsedge did not effect shoot height but increased shoot number by 33% at 100 ppm and decreased tuberization by 57% (Table 6.2). Similar results were observed in 1999 when 3 WAE applications at 100 ppm increased shoot number by 36% and decreased tuberization by 90%.

Findings from the preliminary greenhouse studies suggest that BA + GA increase purple nutsedge vegetative growth at the expense of tuber production. Therefore, since the perennating nature of purple nutsedge is reduced, herbicides which control the above ground portion of purple nutsedge should be effective in reducing populations regardless of translocation to underground tubers.

Field Study 1998

Based on the preliminary glasshouse experiments, field studies were conducted to determine the effectiveness of pre-conditioning purple nutsedge with BA + GA at 100 and 300 ppm 3 weeks prior to herbicide application.

There was a significant treatment by herbicide interaction ($P<0.05$) for both purple nutsedge control and subsequent re-infestation. A sequential herbicide application 3 and 6 WAE nearly doubled purple nutsedge control over a single herbicide treatment at 3 weeks, regardless of the herbicide evaluated (Table 6.4). Applying BA + GA (at either 100 ppm or 300 ppm) 3 weeks prior to application of either paraquat or MSMA provided control comparable to that observed with sequential applications of these herbicides. Pre-conditioning purple nutsedge with BA + GA prior to glyphosate application did not improve control over that observed with a single application 3 WAE.

Regrowth data following herbicide application in 1998 was consistent with the level of foliar control observed. Herbicide timing or BA + GA had no effect on purple nutsedge re-infestation following herbicide application with paraquat (Table 6.4). There was no difference in re-infestation between a single application of MSMA at 3 WAE or applying BA + GA 3 weeks prior to MSMA 6 WAE. A sequential application of MSMA

resulted in 75% less purple nutsedge shoots compared with a single application of MSMA. Similar results were observed with glyphosate, where a sequential application reduced purple nutsedge re-infestation by 85% compared with a single application.

Glyphosate was the only herbicide where pre-treatment with BA + GA reduced purple nutsedge re-infestation compared with a single herbicide application without pre-treatment. Therefore, additional field experiments were conducted in 1999 to further examine pre-conditioning purple nutsedge with BA + GA to facilitate control with glyphosate and other herbicides.

Field Study 1999

A treatment by experiment interaction ($P>0.05$) was not observed for either purple nutsedge control or subsequent re-infestation and data was therefore pooled across May and June experiments. The main effect, +/- PPI application of BA + GA at 380 L/ha, was not significant ($P>0.05$) and data was pooled over PPI treatment for both initial purple nutsedge control and subsequent re-infestation. A significant treatment by herbicide interaction ($P<0.05$) was observed for both purple nutsedge control and subsequent re-infestation.

Sequential herbicide treatments in 1999 were most effective for purple nutsedge control, similar to 1998. When sequential applications were employed, there was no difference between glyphosate and imazapic. Int imazapic was more effective than glyphosate when only a single application was utilized (Table 6.5). Single applications of halosulfuron resulted in ≤50 control and was improved to 83% by applying a sequential

treatment. Pre-conditioning purple nutsedge with BA + GA offered no initial control advantage over no pre-treatment for any herbicide evaluated in 1999

There was no difference between glyphosate or imazapic within each application timing for reducing subsequent re-infestation of purple nutsedge (Table 6.5) Halosulfuron was less effective in reducing subsequent re-infestation than either glyphosate or imazapic. A sequential application of glyphosate at 3 and 6 WAE was more effective than glyphosate at 6 WAE Application timing with either imazapic or halosulfuron did not affect re-infestation Pre-conditioning purple nutsedge with BA + GA 3 weeks prior to glyphosate or imazapic increased purple nutsedge infestation. Shoots increased 128% with glyphosate and 387% with imazapic compared to single herbicide applications at 6 weeks without BA + GA

The objective of these experiments was to evaluate the influence of PGRs and herbicides on purple nutsedge control and population reduction. In 1998, paraquat and MSMA were evaluated and no advantage was observed from pre-conditioning with PGRs prior to herbicide application Glyphosate was also evaluated in 1998 however results were inconclusive since single herbicide applications were not applied at all possible timings Other investigators have also evaluated pre-conditioning with BA + GA followed by glyphosate and MSMA and noted positive results with this combination. Yogev et al (1996) reported that the combination of hormones with either MSMA or glyphosate reduced tuber numbers to less than two per plant, compared to twenty tubers per plant in the control, and five tubers per plant in the PGR only treatment evaluated 4 months after application However, applying BA + GA 3 weeks prior to herbicides more

than doubled purple nutsedge populations with glyphosate and almost quadrupled with imazapic compared to single herbicide treatments at 6 weeks. Teo and Nishimoto (1973) have also noted that foliar applied BA increased plant populations by stimulating growth.

The conclusion of this experiment is that pre-conditioning with BA + GA does not facilitate its control with herbicides. Purple nutsedge control and population reductions were more effective when sequential applications of glyphosate or imazapic were applied. It has been widely documented that BA + GA promotes the release of apical dominance when applied to purple nutsedge (Chetram and Bendixen 1974, Teo et al. 1973). Further research investigating the addition of BA + GA with herbicide tank mixes may provide a better means of utilizing these PGRs to increase herbicide translocation to under ground reproductive structures because tuber physiological processes are stimulated with these hormones.

Table 6.1 The effect of benzyladenine (BA) + gibberellic acid (GA) on purple nutsedge growth and development when applied 2 wks 3 weeks after emergence, Gainesville FL 1997

	Height				Shoot					Tuber
BA + GA	2WAT[2]	4WAT	6WAT	8WAT	2WAT	4WAT	6WAT	8WAT	[illegible]	8WAT
ppm	cm				no				gram	no
0	20	21	23	33	4	6	6	12	4 3	6 3
75	31	32	33	34	4	10	10	20	4 0	0 3
125	44	44	43	44	4	12	12	24	4 7	3 0
250	31	31	33	35	3	5	5	15	3 2	[illegible]
375	29	31	31	33	5	9	9	20	3 9	1 7
500	34	34	33	36	4	7	7	20	5 1	[illegible]
625	31	31	32	32	6	10	10	21	3 8	[illegible]
750	31	31	33	33	4	8	8	19	5 0	2 3
875	32	33	33	35	5	9	9	19	4 2	2 7
1000	32	37	35	35	6	9	9	22	5 0	3 0
LSD 0.05	9	7	6	6	NS	5	5	6	NS	3 7

[1] Promalin®, a proprietary formulation of 1 8% N⁶ benzyladenine (BA) plus 1 8% gibberellin $_{4+7}$ (GA), Abbott Laboratories North Chicago IL

[2] Weeks after treatment applied

Table 6.2 The effect of benzyladenine (BA) and gibberellic acid (GA) on purple nutsedge growth and development 4 weeks after application, Gainesville, FL March 1998

					Biomass		
BA + GA[1]	Timing[2]	Height	Shoot	Tuber	Above ground	Below ground	Above / Below
ppm	week	cm	no		gram	gram	ratio
0	1	57	8	10	4.7	2.4	2.2
0	3	60	27	30	10.7	7.0	1.6
0	6	55	34	17.3	14.4	22.0	0.7
25	1	56	11	1.3	5.9	2.8	1.3
25	3	59	33	2.0	9.4	8.8	1.1
25	6	57	31	6.5	13.2	18.7	0.7
50	1	55	6	0.3	4.9	2.8	1.7
50	3	55	31	1.5	8.3	7.9	1.3
50	6	59	32	3.0	14.1	20.2	0.7
100	1	56	9	0.3	5.2	2.8	1.8
100	3	52	36	1.3	9.2	11.0	0.9
100	6	59	37	1.3	13.6	21.2	0.6
200	1	54	7	1.0	4.8	2.9	1.7
200	3	65	31	0.8	10.6	7.7	1.4
200	6	58	35	5.3	13.2	18.6	0.7
300	1	58	6	0.5	4.0	2.9	1.7
300	3	53	28	0.3	8.4	9.3	1.0
300	6	61	36	6.8	15.0	17.7	0.9
LSD (0.05)		NS	4	1.7	2.7	4.3	0.6

[1] Promalin®, a proprietary formulation of 1.8% N[6]-benzyladenine (BA) plus 1.8% gibberellin $_{4+7}$ (GA) Abbott Laboratories, North Chicago IL.

[2] Week after purple nutsedge emergence for initial BA + GA application

Table 6.3 The effect of benzyladenine (BA) and gibberellic acid (GA) on purple nutsedge growth and development 4 weeks after application, Gainesville FL March 1999

					Biomass		
BA + GA	Timing[2]	Height	Shoot	Tuber	Above ground	Below ground	Above / Below
ppm	week	cm	no		gram	gram	ratio
0	1	21	10 0	0 8	2 7	1.8	1 8
0	3	12	12 0	3 0	3 9	2 7	1 4
0	6	17	17 0	10 3	9 5	9 8	1 0
25	1	25	13 5	0.5	4 4	2.7	1 7
25	3	14	14 0	1 0	6 1	4 4	1 4
25	6	31	31 3	4 8	13 7	13 0	1 1
50	1	26	13 8	0 5	2 9	1 8	1 8
50	3	14	13 8	1 0	5 8	4 7	1 4
50	6	21	21 3	2 3	8 0	8 4	1 0
100	1	27	11 3	0 3	5 2	4 3	1 2
100	3	16	16 3	0 5	5 0	4 1	1 3
100	6	26	26.0	2 3	8.6	9.2	1 0
200	1	36	10 0	0.5	4 0	2 4	1 7
200	3	13	12 8	2 0	6 5	5 1	1.3
200	6	22	21 5	2.3	12 3	14 4	0 9
300	1	36	10 0	1 0	4 6	2 4	2 0
300	3	14	14 0	2.0	8 1	8 0	1 2
300	6	25	25 0	2 5	9.2	7 6	1 2
LSD (0.05)		3 8	5.0	1 3	2.2	2 7	0 5

[1] Promalin® a proprietary formulation of 1 8% N^6 benzyladenine (BA) plus 1 8% gibberellin $_{4+7}$ (GA), Abbott Laboratories North Chicago, IL.

[2] Week after purple nutsedge emergence for initial BA + GA application

Table 6.4 The effect of herbicide and benzyladenine (BA) plus gibberellic acid (GA) on initial purple nutsedge control 9 weeks after emergence and impact on subsequent re infestation, Jay, FL June 1998 [1]

Treatment[2]	Timing	Paraquat	MSMA	Glyphosate
		% control		
1 herbicide	3WAE	28	43	54
2 herbicide herbicide	3WAE 6WAE	54	88	93
3 BA + GA (100 ppm) herbicide	3WAE 6WAE	55	73	65
4 BA + GA (300 ppm) herbicide	3WAE 6WAE	48	78	60
LSD (0 05)			9	
		shoots / 0 25 m^2		
1 herbicide	3WAE	111	91	55
2 herbicide herbicide	3WAE 6WAE	102	21	7
3 BA + GA (100 ppm) herbicide	3WAE 6WAE	122	108	3
4 BA + GA (300 ppm) herbicide	3WAE 6WAE	129	126	3
LSD (0 05)			31	

Entire study was initially cultivated in an area naturally infested with purple nutsedge and treatments were applied following emergence Paraquat applied at 0 6 kg/ha, MSMA at 2.2 kg/ha, and glyphosate at 1 1 kg/ha Purple nutsedge re-infestation in untreated check was 130 shoots / 0 25 m

[2] BA + GA = Promalin®, a proprietary formulation of 1.8% N^6 benzyladenine (BA) + 1.8% gibberellin$_{4,7}$ (GA), Abbott Laboratories, North Chicago IL.

Table 6.5 The effect of herbicide and benzyladenine (BA) plus gibberellic acid (GA) on initial purple nutsedge control 9 weeks after emergence and impact on subsequent re infestation, Jay FL pooled over May and June 1999 [1]

Treatment[2]	Timing	Glyphosate	Imazapic	Halosulfuron
		% control		
1 herbicide	3WAE	69	89	48
2 herbicide	6WAE	53	53	50
3 herbicide	3WAE	93	95	83
herbicide	6WAE			
4 BA + GA (100 ppm)	3WAE	60	54	49
herbicide	6WAE			
LSD (0.05)			7	
			sprouts 0.25 m^2	
1 herbicide	3WAE	58	26	129
2 herbicide	6WAE	91	41	195
3 herbicide	3WAE	33	7	142
herbicide	6WAE			
4 BA + GA (100 ppm)	3WAE	208	200	170
herbicide	6WAE			
LSD (0.05)			69	

[1] Entire study was initially cultivated in an area naturally infested with purple nutsedge and treatments were applied following emergence. Glyphosate applied at 1.1 kg/ha, imazapic applied at 0.07 kg/ha, and halosulfuron at 0.07 kg/ha. Purple nutsedge re-infestation in untreated check was 200 shoots / 0.25 m^2.

[2] BA + GA = Promalin®, a proprietary formulation of 1.8% N^6 benzyladenine (BA) + 1.8% gibberellin$_{4,7}$ (GA), Abbott Laboratories, North Chicago, IL.

CHAPTER VII

INFLUENCE OF COTTON (*GOSSYPIUM HIRSUTUM*) SHADING ON THE GROWTH AND DEVELOPMENT OF PURPLE NUTSEDGE (*CYPERUS ROTUNDUS*)

Introduction

Purple nutsedge is one of the most common and troublesome weeds for cotton producers in the southeastern U S (Dowler 1998). It has been cited as a significant weed problem in 52 crops of 92 countries (Holm et al 1977) and can be found throughout most warm climates. The weed thrives in ideal crop conditions including high moisture fertility, and warm temperatures. Only cool temperatures and moisture limit its distribution (Bendixen and Nandihalli 1987). Though it is relatively short in stature, it is very aggressive. Reproductive propagules (tubers) which are either quiescent or dormant in the soil provide for fast initial growth enabling an early season advantage in crops. Germinating tubers will begin to sprout aerial shoots within 7 to 10 days (Hauser 1962b). Elmore et al (1983) reported that by 1 week after planting, purple nutsedge was significantly taller than cotton.

Purple nutsedge is sensitive to shade (Ranade and Burns 1925). Once crops form a dense canopy, the weed is shaded and the competitive potential of purple nutsedge is reduced. Patterson (1982) found that shading reduced the production of tubers by decreasing partitioning of plant biomass to tubers and rhizomes, with an increase of

partitioning into leaves. Crop interference may also reduce tuber number and size. However, purple nutsedge can still be competitive under a crop canopy with 44 to 70% of the weed's dry weight in underground rhizomes and tubers (Williams 1982).

Purple nutsedge has been designated as one of the world's worst weeds because it is difficult to control. The rapid early season growth of purple nutsedge coupled with cotton's slow growth makes nutsedge control in this crop especially critical and difficult. Conventional weed control in cotton generally includes tillage, and/or herbicides. However, there are few herbicides that have activity on purple nutsedge that also kill tubers (Hammerton 1974), and cultivation may actually lead to an increase in tuber numbers (Rao 1968).

Understanding adaptive factors that influence purple nutsedge growth may be instrumental in achieving greater understanding of purple nutsedge biology / cotton interaction. Understanding these interactions may lead to more effective control of the entire plant including the tuber, the source of most new plants (Holm et al. 1977). The purpose of this experiment was to characterize the growth and development of purple nutsedge as influenced by cotton.

Materials and Methods

Field experiments were conducted in 1998 and 1999 at University of Florida's West Florida Research and Education Center located near Jay. The soil type was Red Bay fine sandy loam with 2.2% organic matter, 69% sand, 16% silt, and 15% clay (siliceous, thermic Rhodic Paleudult). The entire test-site was treated with pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] at 0.86 kg/ha pre-plant

incorporated with a rototiller and fluometuron [*N,N*-dimethyl *N'*-[3-(trifluoromethyl)phenyl)]urea] at 1.7 kg/ha pre-emergence for early-season annual grass and broadleaf weed control.

Two single sprouted tubers were planted 8 cm deep in 58 L pots (40 cm diameter) filled with nutsedge-free soil. Soil from the experimental site was sifted to remove any nutsedge tubers prior to pre-emergence herbicide application and was then used as the potting medium. Two pots were buried (with 5 cm remaining above-ground) approximately 1 m apart in 6 m by 12 m plots both with and without cotton.

In half of the plots cotton 'Delta Pine 5415 RR' was planted in 76 cm rows the first week of May in both years of the study using standard production practices (Sprenkel 1996). Where cotton was planted (4 rows per plot), the two pots were placed between the two center rows. Purple nutsedge in open-field (absent crop) and in cotton, received water from irrigation as needed. Four weeks after the experiment was initiated (cotton approximately 3 true leaves above cotyledon), the entire test-site received glyphosate [*N*-(phosphonylmethyl)glycine] at 0.85 kg/ha to remove weeds other than purple nutsedge in the pots. Pots were temporarily wrapped in plastic to protect purple nutsedge from glyphosate injury. Pots and entire plots were then maintained weed-free manually throughout the season so that purple nutsedge growth with and without cotton could be measured in the absence of interference from other weeds.

The treatments were arranged as a split-plot with presence vs. absence of cotton as main plots and sampling times as sub-plot. Environmental conditions and purple

nutsedge growth was measured in both regimes at four sampling times throughout the growing season (3, 6 9, and 12 weeks after cotton emergence (WACE))

Environmental conditions and crop development were recorded at noon for each sampling time including soil and air temperature, cotton leaf stage and height, and purple nutsedge height and shoots/pot (Tables 7 1 and 7 3) At each data collection interval purple nutsedge in each pot were destructively harvested Soil from each pot was rinsed, tubers counted, and above- and below ground portions were separated and oven dried at 70C for 72 hours to determine dry weights Purple nutsedge data from the two pots from each plot were averaged prior to data analysis

Light measurements at each sampling were recorded using a Sunfleck Ceptometer to determine photosynthetically active radiation (PAR) in the 400 to 700 nanometer waveband Ten light readings from each plots were taken 15 cm above cotton canopy and 15 cm above purple nutsedge absent cotton to determine incident radiation (full-sun) (Table 7 1) Where cotton was grown, average fraction of diffuse radiation (PAR transmittance through the cotton canopy) was calculated to determined how much shade purple nutsedge was receiving in the row-middle of cotton Transmittance (%) was calculated by dividing light intensity (PAR) 15 cm above purple nutsedge in under story by the incident radiation (PAR) 15 cm above the cotton canopy

There was no treatment by year interaction ($P \geq 0.05$) for transmittance (%) and data was pooled Three-parameter regression (cubic model) was used to regress

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[1]Decagon Devices, Inc , PO Box 835, Pullman, Washington 99163 Model SF 80 with 80 independent sensors at one centimeter intervals along sensor probe

transmittance (%) of PAR through cotton canopy against weeks after cotton emergence. Nonlinear regression analysis was used to predict the relationship of cotton development and subsequent light interception according to Ratkowski (1990). The model chosen was $T = \exp(-(B_0 + B_1 \times W^2))$ where T = PAR transmittance (%) through cotton canopy, W = weeks after cotton emergence, B_0 = parameter related to y intercept, B_1 = parameter related to weeks after cotton emergence. PROC NLIN was used for non-linear regression techniques, and parameter estimates for B_0 and B_1 were -0.1264 and 0.00215, respectively (SAS 1990).

The experiment consisted of four replications. Purple nutsedge data and environmental conditions (except cotton light interception) was evaluated for homogeneity prior to data analysis and subjected to ANOVA using the General Linear Model procedure (SAS Institute 1987) to test for main effects and interactions.

Results and Discussion

There was no treatment by year interaction ($P>0.05$) for purple nutsedge growth and development data including height, shoot number, tubers, and above- and below-ground dry weights and was therefore pooled over 1998 and 1999. Cotton shading had a significant effect ($P\leq0.001$) on purple nutsedge growth and development (Table 7.2). Unlike other investigators who reported shoot length decreases as a result of shade (Santos et al. 1997), 6 WACE purple nutsedge shoot height was 82% greater in cotton compared with no crop, a trend that was maintained throughout the 12 week experiment.

There was no difference in the number of sprouts/pot 6 WACE. By the final sampling (12 WACE), however, purple nutsedge shoot number under cotton was 37%

tess than purple nutsedge grown in an open-field environment This result is similar to other investigators (Patterson 1982 Santos et al 1997) who reported a negative influence of shade on nutsedge growth.

At the first sampling, 3 WACE, there were no tubers produced by purple nutsedge in either the cotton or open-field system Hauser (1962b) found similar results and stated that the production of dormant tubers may be low in the first weeks of growth with mostly basal bulbs initially produced from the parental tuber Generally in the first 4 weeks after shoot emergence, all tuber enlargements (basal bulbs) at the terminal end of developing rhizomes will produce new plants. The formation of a dormant tuber will begin at 4 to 8 weeks after shoot emergence following the first appearance of flowers (Hauser 1962b Stoller and Sweet 1987) Ten weeks after shoot emergence, Hauser (1962b) reported that most of the tubers produced were singles whereas by 14 weeks after nutsedge emergence chains of tubers were established

Cotton affected the growth of new tubers (Table 7 2) Six weeks into the cotton season purple nutsedge tuber development in the open field system was five fold that of plants growing under cotton. Patterson (1982) found similar results and cited that purple nutsedge grown in 85% shade produced about 7% of the reproductive structures as purple nutsedge grown in full light.

Cotton also affected purple nutsedge dry matter accumulation. Aboveground dry weight of purple nutsedge grown in the cotton under-story was not less than the open field system until 9 weeks into the season, however underground dry weight was reduced

at each observation (Table 7.2). Twelve WACE underground dry weight was almost seven-fold greater in the open field system compared to nutsedge growing under cotton.

As in most crops, the development of a cotton canopy reduced ($P<0.01$) transmission of PAR to the purple nutsedge under-story (Figure 7.1) which consequently decreased surface soil temperatures (Table 7.3). There were no differences in PAR at the first data collection 3 WACE between purple nutsedge grown absent crop or with cotton (Figure 7.1). However, subsequent cotton development decreased average fraction of diffuse radiation for purple nutsedge. Six WACE PAR transmission through the cotton canopy was 88% of incident radiation (full-sun), and was reduced to 10% by 9 WACE. Twelve weeks after cotton emergence PAR transmission was reduced to less than 5% of incident radiation (full-sun), which is at or below the light compensation point of 127.4 $\mu mol\ m^{-2}\ s^{-1}$ for purple nutsedge as reported by Santos et al. (1997) (Figure 7.1).

Numerous reports have cited the influence of light on plant development (Holt 1995, Patterson 1982, Wills 1975, Salisbury and Chandler 1993). The presence of a leaf canopy may alter not only the quantity of light, but also the quality, duration and distribution as well. Nutsedge species are sensitive to shade and reduced light alters morphological characteristics. In these experiments, shade from the cotton canopy was instrumental in inducing etiolated leaves and a reduction in both vegetative and reproductive dry weight. However, the most notable characteristic with regard to population dynamics is a reduction in tuber production from purple nutsedge grown underneath a cotton canopy.

Typical production practices favor a competitive advantage for the crop over the weed resulting in the formation of a dense crop canopy. Investigators have reported that dense canopies producing shade is effective in reducing the competitive nature of weeds and contribute to their control (Holt 1995, Keeley et al. 1979). For example, Keeley and Thullen (1983) reported that weed free periods of 0 to 6 WACE were observed to decrease yield, whereas yellow nutsedge infestation thereafter did not decrease yield.

However, in these experiments with purple nutsedge, reproductive structures were still produced by the plant after the suggested 6 week weed-free period reported for yellow nutsedge in cotton by Keeley and Thullen (1993). Purple nutsedge reproduces almost entirely by tubers (Holm et al. 1977), and one tuber may produce 99 basal bulbs and tubers in 90 days (Rao 1968). Uncontrolled purple nutsedge beyond the weed-free period may impact future populations despite canopy shading since it was observed that 47% of the tubers under a cotton canopy were produced between 9 and 12 WACE (Table 7.2). Therefore, purple nutsedge control measures may be justified beyond what is typically known to reduce yields when considering subsequent crop rotations or nutsedge re-infestation potential.

Table 1 Environmental conditions and cotton growth development, Jay, FL

Sample interval	Date	Incident radiation[1]	Air temperature	Cotton	
				Leaf stage[2]	Height
WACE[3]		μmol $m^{-2}s^{-1}$	Celcius	no	cm
			1998		
3	16 June	2383	37	4	23
6	7 July	2018	35	10	56
9	27 July	2084	34	12	102
12	17 August	2274	35	17	107
			1999		
3	14 June	2420	30	4	10
6	6 July	2118	34	10	46
9	26 July	2025	35	16	89
12	16 August	2324	37	17	100

[1] Average of 40 observations of photosynthetically active radiation, 10 observations per replication, measured 15 cm above cotton canopy

[2] True leaf stage above cotyledonary nodes.

[3] Weeks after cotton emergence

Table 7.2 The influence of cotton on purple nutsedge height, shoot number, tuber production, and above- and below-ground biomass. Jay, FL, pooled over 1998 and 1999.

Purple nutsedge System	Observation interval (WAE)[1]			
	3	6	9	12
	Height			
	cm			
cotton	11 ns[2]	40 ***	64 **	62 **
open-field	11	22	28	29
	Shoot			
	number / pot			
cotton	2 ns	15 ns	16 **	17 **
open-field	2	23	25	27
	Tuber			
	number / pot			
cotton	0 ns	2 **	17 *	32 ***
open-field	0	10	28	88
	Aboveground dry weight			
	gram / pot			
cotton	2.4 ns	3.0 ns	3.4 **	3.0 **
open-field	2.6	6.2	12.3	13.5
	Belowground dry weight			
	gram / pot			
cotton	3.6 **	5.3 *	8.3 **	14.6 **
open-field	5.8	19.6	60.2	101.0

[1] Weeks after cotton emergence observation interval

[2] *, **, and *** are significant within columns at P = 0.05, 0.01, and 0.001 respectively, as revealed by *t*-Test

Table 7.3 The influence of cotton on surface soil temperature, Jay, FL

Purple nutsedge System	Observation interval (WAE)[1] 3	6	9	12
	Surface Soil Temperature 1998			
	Celcius			
cotton	48 ns	45 ns	31 ***	31 *
open field	49	47	38	37
	Surface Soil Temperature 1999			
	Celcius			
cotton	31 ns	39 **	32 ***	31 ***
open field	33	42	42	44

[1] Weeks after cotton emergence observation interval

[2] *, **, and *** are significant within column at P = 0.05, 0.01, and 0.001, respectively, as revealed by *t* Test

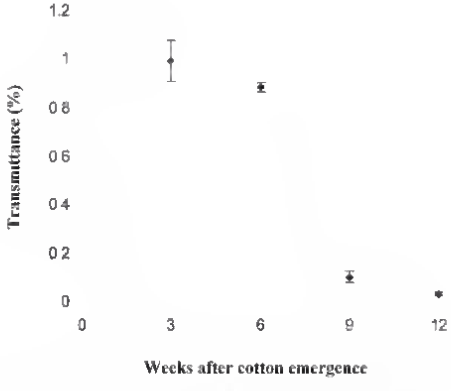

Figure 7.1 Average fraction of diffuse radiation (PAR) measurements 15 cm above purple nutsedge in under-story cotton pooled over 1998 and 1999 Jay FL. Bars following symbols represent standard errors. Regression equation $y = \exp((0.1264 + 0.00215 * x^2))$

CHAPTER VIII
THE EFFECT OF SHADE ON ABSORPTION AND TRANSLOCATION OF GLYPHOSATE IN PURPLE NUTSEDGE (*CYPERUS ROTUNDUS*)

Introduction

Purple nutsedge (*Cyperus rotundus* L.) is a perennial plant that has been designated as one of the world s worst weeds (Holm 1969) Native to India, this sedge has dark green leaves, C-4 photosynthesis, a three-sided stem, and may grow to 100 cm on arable land (Holm et al 1969) Purple nutsedge is also known to the world as "nutgrass due to its extensive underground system of rhizomes and tubers (Hauser 1962a) The plant produces numerous seed however, reproduction is primarily by tubers since only a fraction of the seeds are viable (Justice and Whitehead 1946)

Purple nutsedge has been designated as one of the world s worst weeds because it is difficult to control Conventional weed control generally includes tillage and/or herbicides However, sustainable control is limited because many tubers remain dormant in the soil for an extended period of time eluding typical control measures Control is also limited because many herbicides are not translocated to the underground reproduction structures of purple nutsedge Hammerton (1974) evaluated the effect of both 2,4-D and paraquat for control Even though each of these herbicides was effective in reducing purple nutsedge foliage there was little effect on tuber production and subsequent infestations

More effective control of purple nutsedge has been achieved with glyphosate [*N*-(phosphonylmethyl)glycine] (Zandstra et al. 1974, Bryson et al. 1994). Glyphosate inhibits the enzyme 5-enolpyruvylshikimate-3-phoshate synthase (EPSPS), preventing the plant from synthesizing aromatic amino acids essential for plant growth (Franz 1996). Many investigators have reported that glyphosate is effective for purple nutsedge control due to rapid absorption and translocation to underground rhizomes and tubers (Sprankel et al. 1975, Zandstra and Nishimoto 1977). Translocation of the herbicide to the underground structures is important since the vascular system of below ground structures may stay intact long after aerial shoots have been removed (Hauser 1962b).

The previous chapter discussed how the development of a crop canopy has a negative effect on the growth and development of purple nutsedge. However, purple nutsedge can still be competitive under a crop canopy with 44 to 50% of the weed's dry weight in underground rhizomes and tubers (Hauser 1962a). Patterson (1982) reported that shading significantly reduced purple nutsedge total dry weight, leaf dry weight, leaf area, and total number of shoots. It was also noted from these experiments a reduction in tuber number and size due to a decrease in the partitioning of plant biomass to tubers and rhizomes, and an increase of partitioning to leaves.

Environmental factors affect the degree of control attained with glyphosate. Masiunas and Weller (1988) reported greater phytotoxicity to volunteer potato (*Solanum tuberosum* L.) from glyphosate due to increased absorption in a high temperature regime compared with plants grown in a low temperature regime. Light level did not influence herbicide phytotoxicity with volunteer potato and the temperature by light interaction

was not significant. Light intensity and humidity have also been reported to affect ^{14}C-glyphosate absorption in field bindweed (*Convolvulus arvensis* L.) (Sherrick et al 1986). Plants grown in high light intensity with low humidity resulted in 9% glyphosate absorption compared to 21% absorption in plants grown in low light and high humidity before treatment. Abu-Irmaileh and Jordan (1978) reported a delay in chlorosis when glyphosate treated purple nutsedge leaves were placed in total darkness until plants were subjected to light. Glyphosate has also been reported to reduce fluorescence within 4 hours under light conditions (Madsen et al 1995). However, when 24 hours of darkness followed glyphosate application fluorescence was not diminished until 44 hours after treatment even after receiving several hours of light.

Moosavi-nia and Dore (1979) reported that glyphosate was more active on cogongrass (*Imperata cylindrica* (L.) Beauv.) and purple nutsedge when grown under reduced light intensities due to shading, and attributed an increase in efficacy to morphological differences of the leaf. These investigators also noted a decrease in the regrowth of shoot dry weight of untreated controls as the level of shade increased.

Zandstra et al. (1974) reported stands of purple nutsedge growth was reduced to 74 and 33% of the control after a single treatment with glyphosate at 2 and 4 kg/ha, respectively. More recently Bryson et al. (1994) reported ≥ 75% purple nutsedge control with glyphosate at ≥ 1 kg/ha in reduced tillage cotton. A possible explanation for increased purple nutsedge control with glyphosate in cotton with less herbicide might be attributed to the influence of shading from the crop canopy.

Moosavi-ara and Dore (1979) reported an enhanced toxicity of glyphosate when purple nutsedge is shaded. What is not fully understood is whether enhanced toxicity from shading is from an increase in absorption due to changes in leaf morphology, or whether light conditions affect glyphosate translocation. A greater understanding of glyphosate translocation as influenced by light conditions may provide a basis for selecting a more optimal timing of herbicide treatments in cropping systems. Therefore glyphosate application decisions could be based on the entire plant system including the tuber, the source of most new plants, instead of foliar control. The objective of this experiment was to further investigate the effect shading on the absorption and translocation of glyphosate in purple nutsedge.

Materials and Methods

Studies were conducted during 1999 in a glasshouse in Gainesville, FL. Purple nutsedge tubers were obtained by sifting soil from a single purple nutsedge population located at the West Florida Research and Education Center in Jay, FL. Tubers were planted in plastic trays (76cm x 76 cm x 15cm) with a peat/soil medium and placed in a greenhouse 4 months prior to experimentation with 30C/20C day/night temperatures and were not limited in moisture or nutrients. One week prior to each study initiation, the peat/soil medium in trays was rinsed away with water to collect dormant or quiescent tubers. Approximately 200 tubers were planted in plastic trays using a peat/soil medium and placed in a growth chamber for 1 week. After 1 week, the peat/soil medium in plastic trays was rinsed away with water and tubers which had initiated a single sprout were planted in plastic pots (15 cm in diameter and 11.5 cm in height) with a peat/ soil

medium. Pots were then placed in a glasshouse and were watered and fertilized as needed.

Half of the purple nutsedge plants were grown for 4 weeks in full sun, and half were grown in shade (80%). At 4 weeks old, purple nutsedge plants were over sprayed with non-radiolabeled glyphosate at 0.85 kg a.i./ha plus a proprietary surfactant, and then ^{14}C glyphosate was applied as discussed later. Treatments were applied at 8:00AM with a hand held micro-applicator equipped with an 8001E spray nozzle, CO_2-pressurized at 210 kPa, delivering a diluent volume of 300L/ha. After plants had dried from non-radiolabeled and radiolabeled glyphosate, half of the full sun-adapted plants were either placed in full sun or shade, and half of the shade-adapted plants were either placed in full sun or shade.

Glyphosate, methyl labeled with ^{14}C (specific activity = 54.0 mCi/mmol, radioactive concentration = 200 μCi/ml) in an aqueous solution, was prepared for application by mixing 0.0676 ml of radiolabeled glyphosate with 0.932 ml of deionized water for a total activity of 40 000 dpm/μl solution. Radiolabeled solution was prepared to deliver glyphosate at approximately 0.85 kg of active ingredient per ha. After plants had dried from the over-spray of non-radiolabeled glyphosate, each plant received a total of 10 μL of radiolabeled glyphosate in 5 droplets for a total activity of 400,000 dpm per plant. The droplets were placed on the youngest fully-expanded leaf on the top third portion of the leaf. The length of the treated area was 5 cm and was marked with a felt-tip pen.

The experiment was split plot in design (full sun vs shade) with light regime prior to herbicide application as the main plots and light regime (full sun vs shade) after application were sub-plots. Artificial shading was provided using a plastic pipe structure wrapped in shade cloth. The shade structure was 70 cm tall, 90 cm wide and 120 cm long and reduced photosynthetically active radiation by 80% which was verified using a light meter (Table # 1). Glasshouse temperature was approximately 14C/24 C and 29C/39C day/night on 24 March and 14 July respectively. Mid-day ambient light intensity in the glasshouse at purple nutsedge canopy level in full-sun was 1660 and 2200 umol/m^2/s^1 on 24 March and 14 July (Table # 1). Prior to herbicide application 4 plant samples from the full sun and shade regime were collected to determine above- and below-ground biomass to characterize the influence shade has on purple nutsedge growth (Table # 1).

Purple nutsedge was harvested 6, 24, and 48 hours after treatment. Purple nutsedge plants were harvested by excising the treated leaf and removing the whole plant from the pot to rinse potting soil and separate shoots from rhizomes, roots, and tubers. Plant parts were mounted on 36 cm by 43 cm blotter paper and pressed (Figure # 1), and then air-dried at 70 C for 72 hours. Dried plants were exposed to X-ray film for 40 days in a dark room.

After film development, the autoradiograph hard-copy was converted to a digital format with a desktop flatbed scanner. Because plant parts on the 36 cm by 43 cm autoradiograph film were larger than the flatbed scanner half of the autoradiograph film

was scanned at a time and then re-assembled ("stitched") using Adobe Photoshop®.[1] and saved in 8-bit gray-scale mode (Figure 8 2) Relative amounts of glyphosate absorption and translocation were approximated by using average pixel count, where 255 = black and 0 = white, from exposed X ray film which was obtained using the digitizing software UN SCAN-IT™ *gel* 5 1[2] UN=SCAN-IT™ is typically used to define the band sequence or region In a DNA type protein gel by quantifying average pixel count but was used in these experiments to characterize glyphosate translocation The average pixel count of 15 observations from the treated leaf, above ground and below-ground plant parts were used for comparison among treatments

Treatments were replicated four times and experiments were conducted twice Herbicide applications for each experiment were made on 24 March and 14 July, 1999 Data were subjected to ANOVA to test for main effects and interactions Means were separated using Fisher's protected least significant difference set at P = 0 05

Results and Discussion

Shade reduced purple nutsedge biomass After 4 weeks of growth purple nutsedge under the shaded light regime had 80 and 94% less shoot and 85 and 96% less below-ground biomass compared with plants grown in full sun in March and July, respectively (Table 8 1) Shade also decreased shoot number by 85 and 87% and increased shoot height by 108 and 58% in March and July

[2] Adobe Systems, Inc – San Jose, CA 95110-2704

[1] Silk Scientific, Orem. UT 84059

The average pixel count on the autoradiograph for the 5 cm spot on the treated leaf was 185 and was not affected by experiment, treatment, or harvest interval (Figure 8.1 and 8.2). The average pixel count on the treated leaf for areas surrounding the 5 cm spot was 79 and was also not affected by experiment, treatment, or harvest interval (Figure 8.1 and 8.2). A treatment by experiment interaction ($P \leq 0.05$) was observed for average pixel count of shoots and below-ground roots, rhizomes, and tubers which prevented pooling. There was also a treatment by harvest interval interaction ($P \leq 0.05$) for pixel count of shoots and below-ground structures in March and July and data was analyzed and presented by harvest interval. Main effect (light regime prior to herbicide application) was significant ($P \leq 0.05$) for pixel count data of shoots and below ground structures in each experiment.

Minimal translocation was observed on autoradiographs at the 6 hour timing in March and was not repeated in July (data not shown). Glyphosate absorption and translocation increased as harvest interval was delayed from 24 hours to 48 hours. Barman et al. (1999) reported similar results of increased translocation of ^{14}C-glyphosate over time in purple nutsedge from increased absorption. Pixel count increased by 112% across all treatments 48 hours after treatments compared to 24 hours to shoots in March, but was only 14% higher in the July experiment (Table 8.2).

Similar translocation results were noted in the below-ground structures. Average pixel count for below ground structures increased 133% in March and only 68% in July as harvest interval was delayed from 24 hours to 48 hours (Table 8.3). A probable explanation for more glyphosate translocation at the 24 hour harvest interval in July than

March were higher temperatures in July. The day/night temperature in March at application was 24C/14C compared to 39C/29C in July (Table 8.1). Coupland (1983) also reported a positive correlation to high temperatures with glyphosate translocation in quackgrass (*Agropyron repens* (L.) Beauv.).

Regardless of light treatment, ^{14}C glyphosate moved from the treated leaf to regions above the treated leaf to adjacent shoots, and to roots, rhizomes, and tubers. In general, greater translocation of ^{14}C glyphosate in shoots and below ground structures was observed in purple nutsedge grown in shade prior to herbicide application compared to plants grown in full sun (Figure 8.1 and 8.2). It is presumed that leaf morphological characteristics from shaded conditions such as thinner leaves and less cuticle attributed to greater glyphosate absorption, thus providing more herbicide for translocation. However, light levels following herbicide application also affected translocation.

Light regime following ^{14}C-glyphosate application of purple nutsedge grown in full sun did not affect pixel count of shoots 24 or 48 hours after treatment in March (Table 8.2). An 8-fold and 3.5-fold increase in pixel count 24 and 48 hours after treatment was observed in shoots of shade plants when shade followed ^{14}C-glyphosate application compared to shade plants placed in full sun after herbicide application in March. Light regime following application also limited translocation in shoots of shade plants at 24 and 48 hours in July. At the 48 hour harvest interval in July, a 3-fold increase of glyphosate translocation in shoots of full sun plants was observed when shade followed application compared to full sun. Subsequently, there was no difference in pixel count of shoots from full sun followed by shade or shade followed by shade treatments.

Light regime following ^{14}C-glyphosate application of purple nutsedge grown in full sun did not affect pixel count in below-ground structures 24 or 48 hours after treatment in March (Table 8.2). ^{14}C-glyphosate translocation in below ground structures increased by 3.3 fold after 24 hours and more than doubled after 48 hours in shade plants from a shade regime following ^{14}C-glyphosate application compared to a full sun regime in March. In July, light levels following application to plants grown in full sun after 24 hours did not affect ^{14}C glyphosate translocation, but was increased by almost 3-fold when placed in shade for 48 hours prior to harvest. ^{14}C-glyphosate translocation in underground structures of shade plants was not influenced by light levels following application in July after 24 or 48 hours.

Movement of ^{14}C-glyphosate in several weeds and crops have been reported. Generally, movement of herbicides that are translocated in plant vascular systems are related to the amount of herbicide absorbed, sink-source relationships within the plant, and environmental conditions (Banuan et al. 1999, Devine et al. 1983). The study presented here addresses the influence of light on the absorption and subsequent translocation of ^{14}C-glyphosate. Previous research presented by Moosavi nia and Dore (1979) suggests that purple nutsedge control with glyphosate increased as a result of shade compared to those grown in full sun. Reasons given previously for greater efficacy in shaded plants included an increase in glyphosate absorption from more leaf area and/or a reduction in leaf and cuticle thickness.

Data presented in these studies imply that not only light intensity before application influences purple nutsedge efficacy with glyphosate, but that light intensity

following application is critical as well. Full sun following glyphosate application on plants grown in shade generally resulted in less translocation than when continued under a shaded regime. A possible explanation for this may be attributed to photoinhibition since shaded plants were not adapted to full sun conditions resulting in physiological stress thus limiting translocation. However, photoinhibition does not explain why purple nutsedge grown in full sun followed by full sun in July resulted in less glyphosate translocation in shoots and below-ground structures than either full sun followed by shade or shade followed by shade.

A possible explanation for greater glyphosate translocation under shaded conditions following application may be the effect glyphosate has on carbon assimilation. Glyphosate is a phloem mobile herbicide distributed within the plant symplastically in sieve elements. Since glyphosate has little effect on the water potential of sieve element contents, its distribution within a plant is dependent upon processes that maintain phloem translocation (Geiger and Bestman 1990, Geugler and Geiger 1981). Glyphosate has been shown to inhibit net carbon exchange within an hour of application as irradiance levels were increased (Shieh et al. 1991). Factors contributing to changes in net carbon exchange in these experiments were due to decreases in ribulose bisphosphate carboxylase (rubisco) activity from a build up of shikimate with a subsequent increase in ribulose bisphosphate (RuBP) and a decrease in phosphoglyceric acid (PGA) (Servaites et al. 1987). Shieh et al. (1991) demonstrated that photosynthesis rates of sugar beet (*Beta vulgaris* L.) treated with glyphosate increased as irradiance increased to 400 $\mu mol/m^2/s^2$ but then declined as the light level increased beyond 500 $\mu mol/m^2/s^2$ due to

photoinhibition Therefore it is possible, that in glyphosate treated tissues with reduced light levels there may be more sucrose produced contributing to greater mass flow of assimilated carbon thus promoting herbicide translocation

Purple nutsedge control with glyphosate has been shown in many of the experiments presented in this manuscript to be rate dependent, where an increase in glyphosate rate increased purple nutsedge control Glyphosate rate was generally critical for control only at the first application In the purple nutsedge timing study with glyphosate mid-season control did not improve with increased glyphosate rates in the cotton study, but increasing glyphosate rate among sequential applications did increase control in the non-crop fallow study Data presented in this chapter suggests that shade from cotton canopy closure may be the mechanism contributing to better purple nutsedge control with glyphosate

Table 8.1 Environmental conditions prior to herbicide application and effect on purple nutsedge growth, Gainesville, FL 1999

Light regime	Ambient light (PAR)	Temperature	Biomass		Shoot	
			Above-ground	Below-ground	Number	Height
	µmol/m²/s[1]	min/max C	g / pot	g / pot	no. / pot	cm
			24 March, 1999			
Full sun	1660	14 / 24	4.2 a[1]	2.0 a	13 a	24 a
Shade (80%)	350	14 / 24	0.8 b	0.3 b	2 b	50 b
			14 July, 1999			
Full sun	2200	29 / 39	8.2 a	5.6 a	19 a	33 a
Shade (80%)	420	29 / 39	0.5 b	0.2 b	2.5 b	52 b

[1] Means within a column followed by different letters within each date are significantly different from each other according to the T-test at the 0.05 level

Table 8.2 The influence of light regime on ^{14}C-glyphosate absorption and translocation in purple nutsedge shoots as indicated by average pixel count on autoradiograph, Gainesville, FL

Light regime prior to application	24 hrs after treatment		48 hrs after treatment	
	Light regime following application			
	Full sun	Shade (80%)	Full sun	Shade (80%)
	Average pixel count			
	24 March, 1999			
Full sun	4	6	12	17
Shade (80%)	6	48	25	82
LSD (0.05)	8		35	
	14 July, 1999			
Full sun	25	39	16	53
Shade (80%)	36	66	45	79
LSD (0.05)	25		28	

[1] Average pixel count (where 255 = black and 0 = white) was generated using digitizing software UN-SCAN-IT™, Silk Scientific, Orem UT 84059

Table 8 3 The influence of light regime on ^{14}C-glyphosate absorption and translocation in purple nutsedge roots rhizomes, and tubers as indicated by average pixel count on autoradiograph, Gainesville FL [1]

	24 hrs after treatment		48 hrs after treatment	
	Light regime following application			
Light regime prior to application	Full sun	Shade (80%)	Full sun	Shade (80%)
	Average pixel count			
	24 March, 1999			
Full sun	5	6	11	10
Shade (80%)	7	30	29	63
LSD (0 05)	7		17	
	14 July, 1999			
Full sun	14	18	16	60
Shade (80%)	40	41	56	55
LSD (0 05)	18		26	

[1] Average pixel count (where 255 = black and 0 = white) was generated using digitizing software UN-SCAN-IT™ Silk Scientific Orem UT 84059

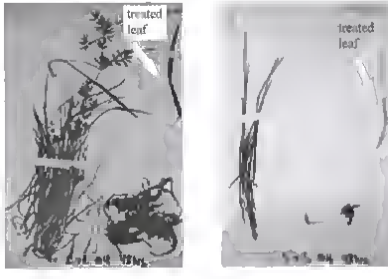

Figure 8.1 Pressed plant for autoradiograph to illustrate the influence of light regime on glyphosate absorption and translocation. Illustrations include: 1. Purple nutsedge grown in full sun for 4 weeks prior to glyphosate application. 2. Purple nutsedge grown in shade (80%) for 4 weeks prior to glyphosate application.

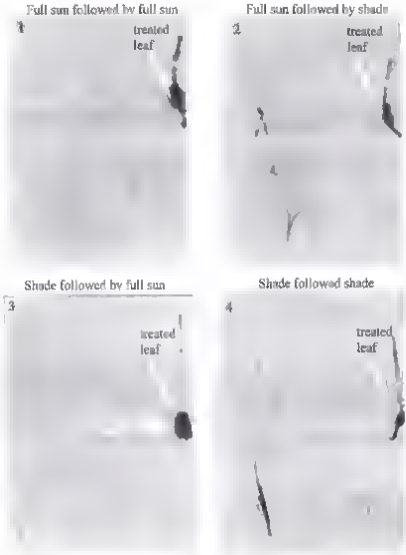

Figure 8.2 Autoradiograph to illustrate the influence of light regime on glyphosate absorption and translocation 48 hours after application. Illustrations include 1 Purple nutsedge grown in full sun followed by full sun after glyphosate application 2 Purple nutsedge grown in full sun followed by shade (80%) after glyphosate application 3 Purple nutsedge grown in shade (80%) followed by full sun after glyphosate application 4 Purple nutsedge grown in shade (80%) followed by shade (80%) after glyphosate application.

CHAPTER IX
SUMMARY AND CONCLUSIONS

Purple nutsedge (*Cyperus rotundus* L.) is a perennial plant that has been identified as one of the worst weeds in the major agricultural areas of the world because it is difficult to control (Holm 1969). Control is limited because of the few herbicides that have activity on purple nutsedge do not affect viability of the underground reproductive tubers, but rather the above-ground, vegetative portion of the plant. Therefore, selective herbicides at best will only result in temporary purple nutsedge suppression.

Glyphosate is a broad-spectrum, non-selective herbicide, thus its use is limited for selective weed control in agronomic crops. However, with the advance of genetic engineering, cotton and soybean varieties have been developed which possess tolerance to glyphosate, thus providing new alternatives for weed management in such crops.

Numerous investigators have documented that glyphosate is effective on many perennial weeds, including purple nutsedge. However, limited data is available that defines the optimal rate and timing of glyphosate application for purple nutsedge control in glyphosate-tolerant cotton. In the studies reported herein, all glyphosate treatments resulted in yield increase compared to no postemergence treatment. Generally, there was an advantage for increased purple nutsedge control when application was delayed until nutsedge size was 20 to 30 cm instead of 8 to 15 cm. However, delaying glyphosate

application in cotton increased purple nutsedge competition causing substantial cotton injury. Sequential applications proved more effective than a single application, but there was no difference whether the sequential treatment was application postemergence (POST) over-the-top or POST-directed. There was also a glyphosate rate response for purple nutsedge control at the initial application, where an increase in rate increased control. However, there was generally no rate response observed with the sequential application. Based on data collected in these experiments, glyphosate at 0.85 kg/ha should be targeted early in the season for purple nutsedge control at approximately the 3-leaf cotton stage. Since there was no advantage in applying the sequential treatment POST over the top, POST-directed treatments should be timed at 8-leaf cotton. Glyphosate at 0.85 kg/ha applied POST at the 3-leaf cotton stage followed by POST directed at 8-leaf should provide good purple nutsedge control and provide cotton the greatest competitive advantage.

Another objective of these studies was to determine the influence glyphosate application has on cotton boll development and yield. Current labeling restrictions allow over-the-top applications of glyphosate up to the 4-leaf stage, and applications made beyond the 4-leaf stage should be POST-directed. These experiments investigated over-the-top applications up to the 12-leaf cotton stage to gain better knowledge of tolerance and potential fruit-loss in late-season applications with glyphosate. These studies were implemented because optimal glyphosate timing for weed control may not be conducive to optimal cotton growth. Topical applications of glyphosate did not adversely affect any cotton, Deltapine 5415RR, growth parameter when timed at the 4-leaf or 6-leaf stage in

1997 or when applications were delayed up to 10 leaf in 1998 and 1999. Furthermore over the-top applications of glyphosate generally did not cause a yield reduction until the 12 leaf cotton growth stage. Cotton 'DP 5415RR' was found to be very tolerant to glyphosate and would provide growers in Florida's panhandle with application flexibility without the fear of severe boll loss. MSMA was also included in this experiment to test cotton tolerance because many farmers still rely on this traditional herbicide for weed control. Most cotton growth parameters were not affected by MSMA when applied POST up to 6 leaf cotton; however, boll loss was observed when applications were delayed until 8-leaf or beyond. Generally, cotton was more tolerant to late-season applications of glyphosate than MSMA, while glyphosate also provided better weed control. Therefore, glyphosate may be a better choice than traditional herbicides such as MSMA for salvage weed control.

Studies were conducted to compare glyphosate against conventional herbicide programs for long-term purple nutsedge control in glyphosate-tolerant soybean and cotton. Changes in tuber density in response to herbicide treatment was monitored over 3 years. In the soybean study, glyphosate was more effective than chlorimuron or imazaquin in controlling purple nutsedge and depleting tubers in the first year of experimentation. However, by mid-season of the second year, purple nutsedge populations were reduced by all herbicides and treatments were comparable. Similar results were noted in the cotton experiment. Glyphosate was more effective for purple nutsedge control in cotton than an MSMA program in the first year. However, MSMA was comparable to glyphosate provided cultivation was also employed with the MSMA

treatment. After 3 years, there was no difference in cotton yield between glyphosate MSMA or cultivation alone, and each treatment substantially reduced purple nutsedge populations.

Data presented in these studies support the conclusion that glyphosate-tolerant crops provide growers with a better option for effective purple nutsedge control in soybean and cotton than traditional control strategies. Good purple nutsedge control was observed with glyphosate without the use of intensive management practices such as cultivation. Furthermore, glyphosate did not affect cotton fruit development or yield when following current labeling restrictions while effectively controlled a typical weed spectrum in Florida's panhandle including purple nutsedge.

This research has increased our understanding of purple nutsedge biology and management practices targeted towards purple nutsedge. Purple nutsedge was observed to be very prolific in both soybean and cotton. However, the combination of typical crop production practices and control measures substantially curtailed purple nutsedge vigor. The reduction of purple nutsedge vigor is important because it subsides tuber production a critical factor for sustainable long term control.

These studies proved that there are weed control options for purple nutsedge control, and that nutsedge can be removed from growers fields in a few short years. Other herbicides that were not as effective as glyphosate proved to control purple nutsedge as well, but not until plant populations were reduced in subsequent years. Regardless of purple nutsedge control strategy in the cropping season, careful attention must made in fallow years. When control measures are removed for purple nutsedge, re-

infestation can quickly occur Therefore, purple nutsedge control programs should be considered not only for cropping systems but also in fallow

Gibberellins, cytokinins, and ABA are plant growth regulators that have been reported to affect the growth of purple nutsedge More specifically, investigators have noted a synergistic effect of benzyladenine (BA) plus gibberellic acid (GA) alters purple nutsedge growth by breaking apical dominance within the tuber chain and promoting vegetative growth at the expense of tuber development. Studies were conducted to further evaluate the influence BA plus GA has on purple nutsedge growth and development The objective of these studies were to determine if BA plus GA would serve to increase control by pre-conditioning purple nutsedge prior to herbicide application In greenhouse studies, BA plus GA had a positive influence on purple nutsedge growth. Generally, purple nutsedge plants were observed to increase in height, shoot number, and decrease tuberization. However, pre-conditioning purple nutsedge with BA plus GA did not increase control with herbicides in field studies. Purple nutsedge control and population reductions were more effective when sequential applications of glyphosate or imazapic were applied instead of BA plus GA followed by these herbicides

The competitive potential of purple nutsedge is reduced under a shaded light regime Experiments were conducted to evaluate the influence cotton has on the growth and development of purple nutsedge Six weeks after cotton emergence incident radiation of purple nutsedge was reduced 88% from the development of a cotton canopy and reduced to 10 and 5% after 9 and 12 weeks By 12 weeks after cotton emergence

photosynthetically active radiation transmission to purple nutsedge under-story cotton was below the light compensation point for purple nutsedge. However, despite very low light levels, 47% of the tubers produced by purple nutsedge under story cotton were developed between 9 and 12 weeks after cotton emergence. This insight justifies purple nutsedge control measures beyond what is typically known to reduce yields, especially considering sequential crop rotations or re-infestation potential.

The influence of shade on absorption and translocation of glyphosate in purple nutsedge was also investigated. Purple nutsedge was grown in a glasshouse for 4 weeks either in full sun or shade (80%). At 4 weeks, plants were over sprayed with glyphosate and then ^{14}C-glyphosate was applied to the youngest fully expanded leaf. Following glyphosate application, half of the full sun plants were placed either in full sun or shade (80%), and half of the shade (80%) plants were placed either in full sun or shade (80%). Treated plants were harvested 24 and 48 hours after treatment. Autoradiograph analysis revealed that glyphosate absorption and translocation increased as harvest interval was delayed from 24 to 48 hours. In general, greater translocation was observed in purple nutsedge grown in shade prior to herbicide application compared to plants grown in full sun. It is presumed that leaf morphological characteristics from shaded conditions such as thinner leaves and less cuticle attributed to greater glyphosate absorption, thus providing more herbicide for translocation. Furthermore, induced shade following herbicide application on either full sun or shade conditioned plants increased glyphosate translocation.

Purple nutsedge efficacy with glyphosate has been shown in many of the experiments presented in this manuscript to be rate dependent, where an increase in glyphosate rate increased purple nutsedge control. In the experiment evaluating the effect of glyphosate rate, purple nutsedge size, and application number in glyphosate tolerant cotton, glyphosate rate was generally critical for control only at the first application. Mid season purple nutsedge control with glyphosate did not improve with increased rates in the cotton study, but increasing glyphosate rate among sequential applications did increase control in the fallow study. Similar results were noted in the long-term purple nutsedge control study where mid season applications of glyphosate at 0.57 kg/ha performed as well for purple nutsedge control and reducing tuber populations as glyphosate at 1.0 kg/ha. Data presented in this manuscript suggests that shade may be the mechanism contributing to greater activity of glyphosate in mid-season applications in cotton. This insight may provide a basis for reduced glyphosate rates in glyphosate tolerant cotton and soybean as canopy closure increases.

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APPENDIX
RAINFALL DATA FOR FIELD EXPERIMENTS

Table A 1 Rainfall at the West Florida Research and Education Center, Jay FL 1997

Day	Month					
	May	June	July	August	September	October
	inches					
1		1 11	0 01			
2			0 30		0 65	
3		0 04				
4	0 15					
5				0 13		
6			0 24			
7			0 50			
8						
9			0 17			
10		0 22			0 01	
11		0 21		1 67	0 03	
12		0 28				
13	0 03	0 44				
14			0 26			
15			0 03			0 07
16			0 75			
17						
18		0 26	0 05			
19		1 09	0 78	0 12		
20	0 69	1 21	0 79	0 30		
21	0 43	0 08	0 78	1 10		
22			0 22			0 10
23			0 72			0 01
24		0 10				0 50
25	1 75	0 32	0 42		0 37	2 24
26	0 25	1 27			0 84	1 30
27		0 11			0 04	0 53
28		2 12	0 24			
29	0 34		0 07			
30	0 09	0 25	0 12			
31			0 06			
Total	3 73	9 11	6 51	3 32	1 94	4 75

Table A 2 Rainfall at the West Florida Research and Education Center Jay FL 1998

Day	Month					
	May	June	July	August	September	October
	inches					
1	0 03			0 35		
2			0 15		0 35	
3			0 52		1 78	
4	0 55		0 01			
5			0 28			
6	0 01	0 68				
7				0 20		0 05
8						0 16
9			0 70	0 72		
10					0 30	
11						
12				0 85		
13				0 15		
14			1 20	1 20		
15			0 25			
16			0 15	0 88		
17						
18				0 02		
19						
20				0 04	0 92	
21			0 67		1 00	
22		0 28	0 21		0.30	
23		0 01		0 01		
24						
25			0.27			
26						
27	0 80					
28					12 0	
29	0 80		0 66		4 98	
30	0 80		0 15		0 10	
31			0 10			
Total	2 99	0 97	6.29	4 42	21 73	0.21

Table A 3 Rainfall at the West Florida Research and Education Center, Jay, FL 1999

	Month					
Day	May	June	July	August	September	October
			Inches			
1		0 02				
2			0 16			
3				0 02		
4			0 3			0 52
5	0 10					0 83
6	0 01				0 29	0 01
7	0 20	0 68	0.31			
8			0 52	0 73		0 01
9			0 02		0 03	
10		0 63		0 12		3 05
11			1 59			
12						0 05
13	0 18	3.36	0 65			
14	0 02			0 25		
15		1 47	1 75			
16		1 0				
17		0 82				
18						
19	0 36					
20				1 18	0 08	
21			0 05			
22						
23				0 41		
24	0 91	0 12				
25		0 41		0 4		
26	0 4		0.6	0 2		
27	2 2					
28						
29	1 66			0 4	0 92	
30			0.52		0 01	
31						
Total	6 04	8.51	6 47	3 71	1 33	4 47

BIOGRAPHICAL SKETCH

Michael W. Edenfield was born January 28, 1970, in Lakeland, FL. In his elementary school years he lived in Fort Walton Beach, FL. In 1983 his family moved to Bowling Green, FL, where he attended Hardee County Jr. High. In his freshman year of high school his family moved to Parrish, FL, where he lived and attended Palmetto High School. In high school he was active in athletics and the local chapter of Future Farmers of America. Following high school graduation in 1988, he began courses in pursuit of an Associate of Arts degree. After graduating from Daytona Beach Community College in 1992, he continued studies at University of Florida in the College of Agriculture. In 1993 he completed the requirements for the Bachelor of Science degree with a major in agriculture economics. His interest in agriculture led him to continue studies in agronomy, and in 1995 graduated with dual majors, agronomy and agriculture economics.

In May of 1995, he enrolled in the College of Agriculture at the University of Florida to pursue a Master of Science in agronomy under the supervision of Dr. D.L. Colvin. The major area of his graduate studies focused on weed control in agronomic crops. Following completion of his Master of Science in August, 1997, he began pursuing a Ph.D. in agronomy, weed science under the supervision of Dr. B.J. Brecke at the West Florida Research and Education Center. Doctoral studies focused on purple nutsedge control dynamics in glyphosate-tolerant crops. After the completion of graduate studies, he will seek a research position that focuses on weed control in agronomic crops.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy

Barry J. Brecke
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality as a dissertation for the degree of Doctor of Philosophy

Michael E. Kane
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy

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This dissertation was submitted to the Graduate Faculty of the College of Agricultural and Life Sciences and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy

August, 2000

Dean, College of Agricultural and Life Sciences

Dean, Graduate School